Culture-based Fisheries for Inland Fisheries Development

Edited by

V. V. Sugunan , B. C. Jha & M. K. Das

Central Inland Capture Fisheries Research Institute

(Indian Council of Agricultural Research)

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ENHANCEMENT AND CULTURE-BASED FISHERIES – CONCEPTUAL FRAMEWORK

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INTRODUCTION

In India, fisheries have always been playing a pivotal role in the food and nutritional security of people especially in the rural areas. Fish production in the country registered an impressive growth of eight times during the last fifty years. From 0.75 million t in 1950-51, annual fish production has reached 5.6 million t during 1999-00. Over the years, growth in the marine sub-sector has slowed down considerably due to dependence on the wild stocks of fish, which are obviously being over-exploited. Conversely, contribution of inland fisheries to the total fish production has increased from 24-29 % in the 1950s and the 60s, to nearly half during the 1990s (Table 1). During this period, fish production systems in the inland waters have expanded, diversified, intensified and technologically advanced. Most of the inland water bodies are captive ecosystems leaving room for intensive human interventions in the biological production process and thereby holding enormous potential for many-fold increase in fish output. In many developing countries, aquaculture has been given high priority to improve the availability of protective food for their undernourished peoples and also to cater to the overseas trade. However, the irrational growth of fisheries and aquaculture ventures, impervious to environmental norms, can open up a floodgate of new concerns, as evident from the recent Asian experience of prawn culture boom. In recent years, clear signs of over-exploitation of important fish stocks, modification of ecosystems, significant economic losses and international conflicts on management and fish trade have become discernible. This could threaten the long-term sustainability of fisheries and contribution of fisheries to food supply. It has now been realized that living aquatic resources, although renewable, are not infinite and need to be properly managed, if their contribution to the nutritional, economic and social well being of the growing world's population is to be sustained.

Table 1. Increase in fish production in India

	Marine	Inland	**Total**	% of inland fisheries
1950-51	0.5	0.2	0.8	29.0
1960-61	0.9	0.3	1.2	24.1
1970-71	1.1	0.7	1.8	38.2
1980-81	1.6	0.9	2.4	36.3
1990-91	2.3	1.5	3.8	40.0
1997-98	2.8	2.4	5.2	46.2
1998-99	2.9	2.5	5.4	46.3
1999-00	2.9	2.7	5.6	48.2

In spite of the phenomenal increase in fish production during the last five decades, the per capita availability of fish in India continues to be very low at 8 kg per head, against the world average of 12 kg. In order to fulfill the minimum nutritional requirement as stipulated by the WHO standards, a person needs 11 kg of fish/year. Assuming that 56% of the population includes fish in their diet, the country currently needs at least 6.2 million t of fish (Sugunan and Sinha, 2001). Thus, the current shortfall of fish production is about 0.8 million t. Since marine fishery is fast approaching a plateau in growth rate, most of the shortfall in future has to be met from the inland fisheries.

Rivers, estuaries and the lagoons, being under the threat of environmental degradation, are not expected to play a significant role in meeting the additional requirements of inland fish production in India. The country has 14 major, 44 medium and innumerable small rivers, but their fish yield is fast decreasing. Fish production in many stretches of the river Ganga has declined at an alarming rate during the last five decades. Similar fall in yield rate has been reported from the Brahmaputra. Water abstraction, sedimentation, dam construction and other habitat destruction are responsible for the loss of riverine fishery. Fisheries of all the estuaries and lagoons of India are also under threat due to habitat degradation (Sugunan and Sinha, 2001). Unchecked growth of intensive aquaculture may open up many new environmental, social and legal issues. Thus, the eco-friendly option of developing culture-based fishery in small reservoirs and floodplain lakes, coupled with the stock and species enhancement in large reservoirs, hold the key for future inland fisheries development in India (Sugunan, 1995, 1997a, b & 2000).

SUSTAINABLE DEVELOPMENT OF INLAND FISHERIES RESOURCES

Sustainable development, according to the FAO, *is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable* development should be environmentally non-degrading, technically viable and socially acceptable. Sustainability, as applied to fisheries development is relevant to both capture and culture systems and their products, which are designed to maintain productivity and usefulness to society without any time limits (Gopalakrishnan, 1999). However, compared to the intensive aquaculture, capture and culture-based fisheries provide management options, which are more compliant with the norms of sustainable development. Most of the open waters, which contribute substantially to fish production such as reservoirs, *beels*, *boars*, *chaurs* and others, are managed on the basis of culture-based fisheries or various other forms of enhancement, which are intermediate to culture and capture fisheries norms. These modes of fishery management offer relatively eco-friendly options for sustainable management of resources. However, these norms still lack conceptual clarity due to the absence of clear-cut 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.

CAPTURE FISHERIES, CULTURE-BASED FISHERIES AND ENHANCEMENT

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 water quality and other habitat variables. The marine fishery is the example of capture fisheries and the intensive aquaculture of fish and prawn in small ponds is the typical example of 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. 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.

Enhancement

A range of management practices is collectively known as enhancement. FAO (1997) defines fisheries enhancements as technical interventions in existing aquatic resource systems, *which can substantially alter the environment, institutional and economic attributes of the system*. Lorenzen *et al.* (2001) defines it as limited interventions in the life cycle of common pool resources. Enhancement is the process by which qualitative and quantitative improvement is achieved from water bodies through exercising specific management options. The common forms of enhancement which are relevant to inland water bodies of India are stock enhancement, species enhancement, environmental enhancement, management enhancement and enhancement through new culture systems. Culture-based fishery is the most common mode of enhancement being followed in inland water bodies in India. When the fish harvest in an open water system depends solely or mainly on artificial recruitment (stocking), it is generally referred to as culture-based fishery.

The rationale of enhancements is that under certain conditions, limited technological interventions can sustainably increase the utilization of natural aquatic productivity. Stocking of hatchery-reared fish seed, for example, can substantially increase the yields of desired species where natural productivity is high but recruitment of desired species is limited. Habitat enhancements can have similar effects. Because enhancements largely rely upon natural productivity, they require little feed or energy inputs, and can provide high returns to limited investments. Hence enhancement provides opportunities in particular for resource poor sections of inland and coastal aquatic resource users. Moreover, introduction of enhancement technologies in common pool resources may facilitate institutional changes leading to more efficient and sustainable exploitation of resources (Lorenzen *et al.,* 2001).

The global contribution of enhancements to fish production is difficult to ascertain, because yields from enhancements tend to be assimilated into statistics of either capture fisheries or aquaculture production (Lorenzen *et al.,* 2001). There is little doubt, however, that enhancement yields are dominated by culture-based fisheries for freshwater and diadromous species. Annual yields in this category are likely to be around 2 million t, including 1.3 million t from Chinese reservoirs (Huang *et al* 2001), 0.4 million t from salmon in North Pacific (Shaw & Muir, 1987 and Kaeriyama, 1999, Knapp, 1999). Culture-based fisheries for food and recreation are well established components of aquatic resource use in Europe (*e. g.* Mattern, 1999) and in North America where state fisheries organizations expend an average of 19% of their budgets stocking (Heidinger, 1999; Ross & Loomis, 1999). Overall, the estimate of 2 million t per year suggests that culture-based fishery of freshwater and diadromous organisms account for about 27% of recorded capture yields, or 10% of combined capture and culture in this category (total yields 7.5 and 21.2 million t respectively, FAO, 1999).

It has been recorded that 1.6 million t of fish is produced through inland aquaculture in India (Gopakumar, 1999). The remaining 1.2 million t of inland fish is attributable to different types of inland open water systems. Although the breakup of catch from rivers, lakes, floodplain wetlands and reservoirs are not recorded, it is generally believed that the capture fisheries of rivers and estuaries contribute very little to their total inland catch. Bulk of production from open waters emanates from reservoirs, small irrigation impoundments and floodplain wetlands. The main focus of management in these water bodies is culture-based fisheries and fisheries enhancement.

Different forms of enhancements

Enhancement 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) Habitat enhancement,
v) Management enhancement, and
vi) 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 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. There are two types of stock enhancements viz., (1) stocking to create a culture-based fisheries *i.e.*, fisheries based predominantly on the recapture of stocked fish and (2) Stocking to enhance or supplement self recruiting populations.

Species enhancement

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 naturalized populations (Welcomme & Bartley, 1998). 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

Environmental enhancement is improvement of the nutrient status of water by the selective input of fertilizers (Sugunan, 1995, 2000). Although this is a common management option adopted in China (Sugunan, 1997b), a careful consideration of the possible impact on the environment is needed before this option is resorted to in reservoirs.

Habitat enhancement

A wide range of habitat enhancement are being carried out in inland and marine fisheries, using traditional as well as recently developed technologies (*e.g.* Williams *et al.*, 1997, Cowx & Welcomme, 1998; Morikawa 1999). The effectiveness of these measures has often proved difficult to evaluate due to the time scales involved in responses, the levels of natural variation in natural habitat and recruitment, and institutional impediments to monitoring and evaluation (*e.g.* Kershner, 1997; Munro & Bell, 1997). As a result, little scientific guidance can be given with respect to the choice of habitat enhancement technologies.

A common effective habitat enhancement found in tropical Africa and Asia is the construction of brush parks, such as *acadjas* in West African lagoons. Brush parks provide substrate for periphyton production and protection from certain predators in addition to serving as fish aggregating devices. In the lagoons of Benin, production from brush parks has been estimated as 1.9 to 5.6 t/ha/year (Welcomme, 1972) substantially higher than the average of 2.9 t/ha/year achieved in open waters of the lagoons. Similar results he been reported from Nigeria (Solarin & Udolisa, 1993).

Other enhancements

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.

Culture-based fisheries

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*. This management tool is particularly effective in increasing yields when recruitment of desired species is lower than the environmental carrying capacity. This is the case in certain modified ecosystems (*e.g.* reservoirs) or where intensive harvesting has reduced spawning stocks to very low level. Chronic recruitment limitation can also arise naturally in seasonal and /or isolated freshwater bodies, or in marine habitats with poor connectivity to spawning sources (Doherty, 1999). The floodplain wetlands, the small reservoirs and a number of community water bodies in India fall under the above-mentioned situation. Thus, culture-based fishery forms an important management tool in the hands of fishery managers in India to increase production and productivity. The main focus of management here is stocking and recapture. The size at stocking, grow'out period and the size at capture are the important criteria in culture-based fishery management.

DEFINITION OF WATER BODIES

Floodplains: The flat land bordering rivers that is subject to flooding which tend to be most expansive along the lower reaches of rivers

Wetlands: Areas of marsh, fen, peat land 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 meters (Ramsar Convention). It is generally understood that wetlands occupy the transitional zone between permanently wet and generally dry environments.

Floodplain wetlands: Wetlands situated on floodplains of major rivers

Reservoirs: Man-made impoundments, which are created by obstructing the surface flow by dams, anicuts barrages etc., compared to lakes, which are natural water bodies. This includes a large number of small irrigation reservoirs wrongly termed as tanks in the three southern states of Tamil Nadu, Andhra Pradesh and Karnataka. Classification: Small (<1000 ha) medium (1000 to 5000 ha) large (>5000 ha).

Small water bodies (SWB): An array of natural and artificial water bodies, such as small reservoirs, lakes, ponds, floodplain lakes and small river stretches (Anderson, 1987) (excluding: mangroves, Large coastal and inland floodplain, coastal lagoons with intensive, well-established fisheries, and fish ponds specifically constructed for intensive aquaculture).

CONCLUSION

India is one of the richest countries in the world in terms of small water bodies. With nearly 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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PRESENT STATUS OF INLAND FISHERY RESOURCES IN INDIA AND THE NEED FOR THEIR ENHANCEMENT

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INTRODUCTION

India is endowed with vast expanse of inland aquatic ecosystems such as rivers, natural lakes, estuaries, backwaters, mangroves, floodplain wetlands, ponds and tanks. The country is one among the top twelve mega-biodiversity regions of the world. During the post- independence phase, further addition to our inland fishery resource has been made in the form of man-made lakes and canals. The country has the distinction of possessing the second largest inland fishery resource and fish production, next only to China. It is rather difficult to estimate the exact quantity of fish biomass required for human consumption in the country. However, taking 56% of the total population as fish eaters and 11 kg/person/year as the requirement, we would need around 6.2 million t. Since marine fishery has touched its plateau, it is necessary that 3.3 million t should come from the freshwater segment. Considering the present inland fish production is 2.8 million t, the target is steep, but achievable through better scientific management. The onus of achieving the said target rests on the following two aspects:

- *Enhancement of fish production by bringing more and more area under the ambit of aquaculture development with fair degree of rationality in its management,* and

- *Application of scientific management norms for increasing the fish productivity and production from the open water through judicious use of enhancement methods.*

INLAND FISHERY RESOURCES ON INDIA

The major inland fishery resources of India are shown in Table I.

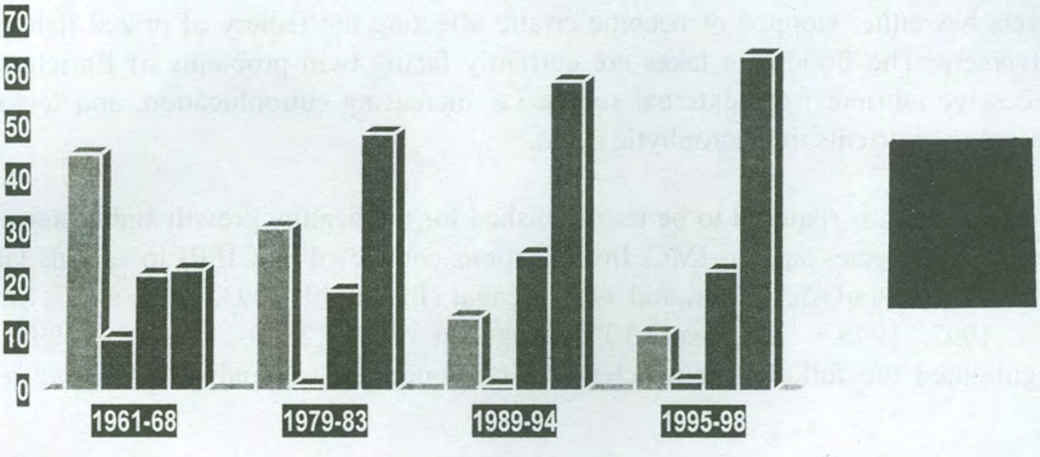
Table 1. Inland fishery resources of India

RESOURCES	RESOURCE SIZE
Rivers (km)	45,000
Canals & Creaks (km)	1,26,334
Reservoirs (ha)	30,20,000
Floodplain lakes (ha)	2,10,000
Estuaries (ha)	27,00,000
Coldwater upland lakes (ha)	72,000
Lagoons (ha)	1,90,000
Ponds & Tanks (ha)	22,50,500

Rivers

The rivers of India are being subjected to stress on account of irrational exploitation of the resource. The impact of various developmental activities on fishery are discernible from the level of recruitment to fish stock, especially prized fishes such as Indian major carps and hilsa. An alarming shift in the population structure of fish species has also become apparent in recent years, as species of lower economic values have occupied the niche at the cost of economically and biologically desirable species. Irrational fishing practices are leading to ecosystem and growth over-fishing. In case of river Ganga, for instance, the fish catch structure has changed considerably (Fig. I) causing hardship to fishers who depend on this resource for centuries.

Fig 1. General Trends of Fishery in river Ganga



Most of the rivers are heading towards a catastrophic situation due to rapid changes in the hydrological regime and other man-induced river valley modifications. The data generated in case of the Ganga indicate that its bed, from origin to Patna, has become a sand desert, 90-98% sand in the benthic soil, (Sinha *et al.*, 1998).

The prized masheer fishery of various river systems in the country has suffered due to the increasing incidence of irrational anthropogenic activities and river valley modifications. The situation is assuming a serious dimension, needing immediate attention for its effective conservation.

The highlights of these negative changes can be summarized as:

- *Considerable decline in fish catch, from 83.5 kg/ha/yr (1958) to 2.55 kg/ha/yr (1995).*
- *The fishery of IMC has declined from 45% in 1960s to 10% in 1990s.*
- *The fishery of miscellaneous fish species including catfish, however, has increased menacingly around 22% in 1960s to more than 60% in 1990s.*
- *The hilsa fishery above the Farakka barrage in river Ganga has touched its nadir, from 14% in 1960s to below 1% in 1990s.*

Floodplain wetlands

The floodplain wetlands of India being the continuum of rivers are known for their high production potential and lucrative fishery. However, man-induced modifications have adversely affected the fishery of these lakes. Massive proliferation of unwanted biota has overshadowed the growth of biota necessary for human welfare. Prior to the construction of flood protection measures, most of the lakes were serving as the feeding and breeding grounds for economically important riverine fish stock. During the post flood construction phase, however, the process of natural recruitment of fish seeds from rivers has either stopped or become erratic affecting the fishery of prized fish species adversely. The floodplain lakes are currently facing twin problems of Enrichment of excessive nutrient from external source i.e. increasing eutrophication, and locking of necessary nutrients in macrophytic chain.

Grazing chain is required to be re-established for the healthy growth and sustenance of prized fish species such as IMC. Investigations conducted by CIFRI in various lakes of Bihar, Uttar Pradesh, Assam and West Bengal (Jha, 1989, 1993, 1995, 1997, Sinha & Jha, 1997, 1998, Sugunan, 1995, Sugunan *et al.*, 2000, Yadava, 1995) have highlighted the following characteristics of floodplain wetlands (i) *Advance to very* *advance stage* of eutrophication, (ii) domination of macrophytes (iii) Gastropods dominated benthic niche, (iv) Forage fish dominated natural fishery, and (v) Continuous and huge accumulations of detrital load at the lake bottom.

The fish production potential of these lakes have been estimated to range from 1000 – 1500 kg/ha/yr, but the actual average fish yield is much low 160 kg/ha in Bihar lakes and 210 kg/ha in West Bengal & Assam lakes. The fact remains that in spite of high to very high productivity potential, the poor fish yield from these lakes is a function of broken grazing chain due to the absence of proper fish grazers necessary to utilize the available natural food resource in the system. For instance, the most dominant biota present at the pelagic niche like macrophytes and at the benthic niche like gastropods remain by and large unutilized due to lack of grazers to feed upon them. The dilemma is that major percentage of available energy either remains unutilized or it goes as waste. Evidently, the channelization of energy is not proper for getting quality fish biomass we value or required for the welfare of mankind.

Reservoirs

Man-made lakes spread over 3.15 million ha constitute the prime inland fishery resource of India. The current fish yield from this resource, however, remains much below the desired level. An average fish yield of 14 kg/ha/yr (large and medium reservoirs) and 49 kg/ha/yr (small reservoirs) has been estimated (Sugunan, 1995). Data available at CIFRI, however, suggest that the fish production potential of reservoirs is much higher than the present yield. Scientific guidelines are available for achieving higher production from the reservoirs. Application of such management practices by all the states will go a long way in increasing the inland fish production in India.

Estuaries

Estuaries are amongst the most productive systems in the world. India has the distinction of having one of the finest and most productive estuarine systems in the world, the Hoogly-Matlah estuarine complex. The annual average fish and prawn production from this estuary has increased in recent years, specially during the post Farakka phase, from 3,204 t (1960-63) to 44,454 t (1999-2000). It is primarily due to substantial increase in winter '*bagnet*' fishery and abundance of freshwater fish species. As the salinity regime of the estuary is on declining due to enhanced discharge of freshwater from the upstream of Farakka barrage, the estuarine zone has been pushed downward towards the mouth.

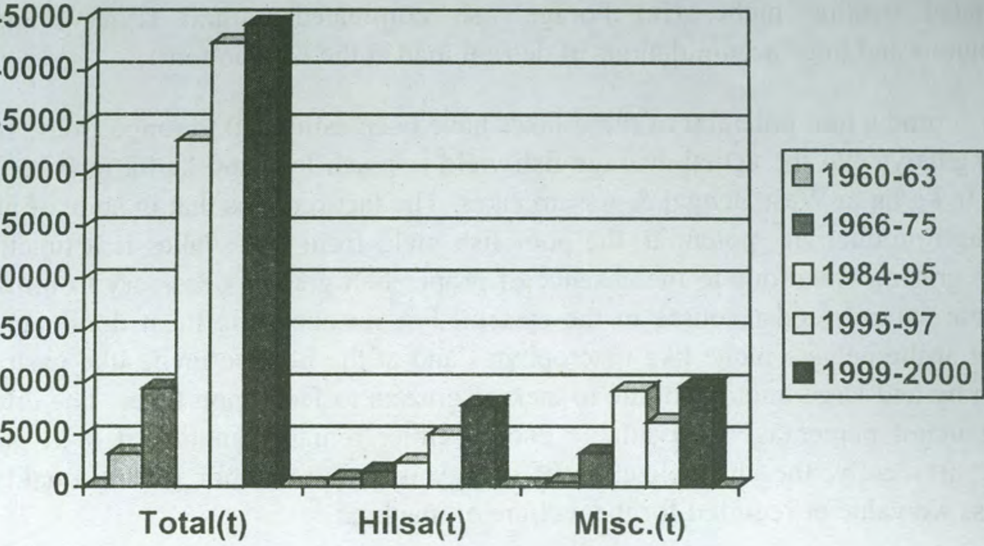


Fig 2: Trends of fishery in Hoogly-Matlah estuarine system

STATUS OF AQUACULTURE

Of the total inland fish production, an estimated 1.38 million t is attributable to aquaculture, the rest coming from all other sources. However, the production potential from aquaculture source has been estimated to 4.5 million t and accordingly there is enough scope for its development.

It is a paradox that, till date, out of the available 2.25 million ha of ponds and tanks, only 0.8 (nearly 19%) million ha could be brought under the scientific fish farming. Even at a moderate level of projection, where 60% of the total resource (1.5 m ha) is brought under scientific aquaculture, at an average yield of 2 t/ha, the country can expect a fish production of nearly 3.0 million t. Similarly, if 1 million ha area is brought under semi- intensive aquaculture practices with moderate production target of 3 t/ha the expected fish production would also be the same i.e. 3.0 million t.

PROSPECTS AND STRATEGIES FOR SUSTAINABLE FISH PRODUCTION FROM OPENWATERS

Rivers

The rivers are highly stressed ecosystems both in terms of their physical entity and ecological integrity. The fishery is a very small component of activities that are being pursued in a river. Loss in physical resource implies the loss of biodiversity and impacting fish and fishery. Nothing very tangible is in sight to rectify the damage already inflicted to the system. However, the following measures have to be undertaken to rectify the situation *viz.*,

- Integrated riverine management approach
- Basin management approach while planning river development
- Rationing of water for various activities among various user groups
- Strict compliance of environmental norms by the target groups for maintaining water quality and biodiversity.

Floodplain wetlands

- Cluster approach for effective management of floodplain lakes.
- Open type lake management should give more emphasis on capture fishery, as natural recruitment of fish seed is common in such water bodies.
- The nature and quantum of natural recruitment should be analysed.
- Effective monitoring of growth and mortality factors is needed.
- To ensure requisite quantum of recruitment certain factors need careful monitoring such as identification and protection of breeding grounds, facilitate smooth passage of fish stock including brooders from lake to rivers and *vice versa*, protection of brooders and juveniles from wanton killing etc.
- Strict ban on the use of unrealistic fishing practices like use of *chatti jal* (fine meshed mosquito clothing nets) so as to save the catch of small sized fish.
- In case of closed lakes culture based fishery should be practised.
- Right species of fish in right number should be stocked for better performance.
- The basic principle in the management of closed lakes should revolve round the size of stocking materials, stocking density, fishing efforts, size at capture and selection of species for stocking.

Reservoirs

Reservoir management in India largely emphasizes the development of carp fishery, specially the Indian major carp fishery. Over emphasis on carp centered management policy, however, poses problem related to utilization of phytoplankton, the most dominant pelagic biota available in Indian reservoirs. A suitable answer to this has to be found in near future to make the reservoir fishery more viable economically. Silver carp is a type of fish, which can fill the slot, but utmost care is required before it is introduced in any openwater ecosystem, as the country can not afford to repeat the development, which has taken place in case of Gobindsagar reservoir.

The small reservoirs, which account for more than 50% under the reservoir resource in the country, need greater attention because of the facts that management of these water bodies are quick and easy to handle. The CIFRI experience suggests that the yield rate from small reservoirs can be increased manyfold. However for better results the following points need careful monitoring *viz.*, (i) The reservoir morphometry and water resident time; (ii) The limno-chemical features of water and soil; (iii) The biota thriving therein; (iv) The relation between physico-chemical features and biotic communities in terms of population and community dynamics.

In order to invoke proper management norms and to fix production targets, rapid assessment of small reservoirs is a must, on the following lines *viz.*, (i) Preparation of inventory along with their potential yield; (ii) Classification of reservoirs as: (a) reservoirs which are suitable for capture fishery alone, (b) reservoirs which have multiple use but indicate high productivity potential, and (c) reservoir with low productivity potential, and so on.

It is apparent that by employing rational and scientifically tested management practices the fish production from reservoirs can be enhanced to manifold.

Estuaries

The conservation of estuarine fishery should form the key for sustainable development. The tendency of over fishing has to be discouraged. The external onslaught of any form, be it pollution, ingress of excessive freshwater, wanton killing of fish and prawn juveniles, over fishing etc. need to be contained so as to obtain sustainable fish catch from estuarine resource. For the effective and rational exploitation of estuarine fishery resources, the following aspects are important *viz.*,

- ❖ The estuarine environment should be exploited rationally without disturbing the natural resources of fish and prawn stocks including their recruitment level.

- Indiscriminate fishing of resources should be avoided by invoking foolproof planning and effective management measures.
- The mesh size regulation of fishing gear like drift gill net, dragnet, seine net should be adjusted in such a way that the capture of juveniles of prawn and fish is avoided.
- Necessary precautionary measures should be taken against over-fishing of hilsa at the mouth of estuaries and coastal regions, which can be done by reducing the fishing efforts on hilsa fishery.
- Some kind of regulatory measures, fishing holiday, must be enforced to protect brood finfish stock
- Collection of prawn or finfish seeds for stocking bheries must be stopped henceforth to save the wanton killing of other species
- Effective monitoring protocol must be developed to stop the ingress of chemicals, pesticides or antibiotics from bheries
- The mangrove forests along with its wetlands which provide stability to the estuarine ecosystem, must be conserved.

Aquaculture

- Expansion of aquaculture activities to unmanaged (derelict waters) and larger sheet of water bodies (lakes and reservoirs)
- Diversification of Aquafarming from traditional culture of only 'table fish' to pearl culture, ornamental fish culture, and shrimp culture
- Efforts to develop multiple cropping system keeping fish at the center stage by augmenting supply of fish seeds round the year
- More efforts to use wastewater for the culture of fish considering it as an important source of energy
- Strengthening the mechanism for transfer of technology
- Ensuring adequate and timely financial support and Institutional credit facilities.

CONCLUSION

Most of the inland waters fall under common property resource and as such a holistic management policy incorporating all the usages together, can be the only answer to get the maximum benefit on sustainable basis, be it fishery, industrial use or public water supply or anything. In the existing scenario, where aberration of aquatic systems has become the order of the day, enhancement of fish production from open waters is a difficult proposition unless pursued on scientific lines. It is time that the future developmental plans should be drawn on the line like "*Conserve the biodiversity we value so as to get sustainable production*".

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Summer School on
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ROLE OF SOIL QUALITY PARAMETERS IN CULTURE BASED FISHERY MANAGEMENT

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INTRODUCTION

Soil is a major component of any aquatic environment. It not only holds water for aquatic animals but also enriches the water body with various nutrients required for biological production. A series of physical, chemical, biochemical and microbial reactions continuously take place at bottom soil resulting in release of different nutrient elements to overlying water. A dynamic equilibrium is maintained between the sediment and water due to their interdependence and thereby exerting a favourable influence on the environment for aquatic animals. It is, therefore, necessary to have a proper knowledge of the more important physical and chemical properties of soil that influence the productivity of any water body.

Soils of floodplain wetlands and reservoirs receive an additional input in terms of organic matter, inorganic minerals and silt and clay through precipitation, incursion of river water and washings from the catchment areas. Moreover, most of the floodplain wetlands are infested with macrophytes which after death are deposited at the bottom and undergo decomposition. Consequently, the nature and properties of bottom soil of such water areas change from year to year. Therefore, soils of such water bodies should be analysed every year in order to determine their actual productivity. The most important physical and chemical properties of soil influencing the productivity are discussed.

IMPORTANT PHYSICO-CHEMICAL PROPERTIES OF SOIL

Texture

Soil texture is an indicator of the proportionate composition of mineral fractions in soil and are grouped into sand, silt and clay depending on the particle size. Clay particles, smallest in size (< 0.002 mm dia.) and exhibit colloidal properties like adsorption and exchange phenomenon in soil. This fraction along with organic matter contents of the soil influence the water holding capacity, exchange of nutrients and fertility status of soil. Sand (>0.02 mm dia.) and silt (0.002-0.02 mm dia.) particles are not very important from the nutritional point of view but perform a very important role in gas exchange and nutrient movement through soil phase to solution phase by providing the required passage to them. Both sandy and clayey soils are not desirable as in the former nutrients are lost due to heavy leaching while in the later, high adsorption capacity impoverish the water from all its nutrients. Loamy soils with a balanced composition of sand (23-52%), silt (28-50%) and clay (7-27%) are considered most productive because they are not too much adsorptive to impoverish water of all its nutrients and at the same time do not permit excess loss of nutrients.

Soil reaction (pH)

pH of soil is one of the most important factors for maintaining the productivity of any water body since it controls most of the chemical reactions. The availability of nutrient elements native as well as added, rate of mineralization of organic matter, fixation of P and other elements and growth and survival of different biotic communities are greatly influenced by pH. Soils are classified as acidic (pH < 7.0), neutral (pH 7.0) and alkaline (pH > 7.0). When sediments contain high organic matter with slower decomposition rate, acidity develops due to humic and short chain fatty acids leading to less productivity. Most of the floodplain wetlands exhibit wide variation in soil pH (4.2-8.5) in different parts of the country. while it is mostly acidic (pH 4.9-5.8) in all the reservoirs under Cauvery, Krishna and Sharavathy river systems. Soil pH in the range of 6.5-7.5 is considered ideal.

Organic matter

Soil organic matter plays a dominant role in maintaining the biological productivity of aquatic ecosystem. It (i) acts as a source of energy for the microbes participating in various biochemical processes resulting in the release of different nutrients, (ii) influences the physical, chemical and biological activities in soil, (iii) improves soil structure, aeration, and (iv) increases water holding capacity, buffering and exchange capacity in soil including solubility of soil minerals. It also serves as a store house of various nutrients essential for biological production and as food source for benthic feeding fishes and invertebrates. Soils of floodplain wetlands and reservoirs contain more organic matter than uplands due to accumulation through autochthonous as well as allochthonous sources. Soils having less than 0.5% organic carbon are considered low productive while those in the range of 0.5-1.5% and 1.5-2.5% are considered medium and high productive respectively.

C/N ration

The carbon to nitrogen (C/N) ratio of soil influences the microbial activity of soil to a great extent and thereby affects the rate of release of nutrients from organic matter. If the C/N ratio is very wide (> 20) most of the mineralized nitrogen will be consumed by the soil microorganisms for their own sustenance. Most productive range of C/N ratio is 17:1 to 10:1. Below 10:1 decomposition is very slow and consequently availability of nitrogen is not up to satisfaction.

NUTRIENT STATUS

A large number of elements are required for biological production. Among these, nitrogen, phosphorus and potassium are termed as primary nutrient elements, calcium, magnesium and sulphur as secondary nutrient elements and boron, copper, manganese, zinc, molybdenum, iron and cobalt as micronutrients on the basis of their requirements

Nitrogen

Nitrogen, being a basic and primary constituent of protein, is required to stimulate primary production in aquatic environments and is essential for the formation of living matter. In soils nitrogen occurs almost entirely in organic form which is gradually mineralized to soluble inorganic nitrogenous compounds (NH_4, NO_3, NO_2) by obligate as well as facultative anaerobes and subsequently utilized by fish food organisms. It is the easily decomposible form of organic nitrogen known as available nitrogen which is important for aquatic productivity. For any productive soil, available nitrogen must be above 250 mg/l. Available nitrogen status of most of the reservoirs and floodplain wetland, soils are conducive for biological production. It was observed that the deep reservoirs contain less amount of available nitrogen than shallow reservoirs.

Phosphorus

Phosphorus is essential for assimilation of nitrogen into cellular matter besides respiration, cell division, metabolism, growth and synthesis of protein. It is considered a key element in maintaining the productivity of aquatic ecosystem. In soil, both organic and inorganic forms of phosphorus occur but organic-P is of little significance in supplying phosphorus to primary producers because of its slower rate of mineralisation under anaerobic condition at the bottom in aquatic ecosystem. The native phosphorus status of most soils are rather low compared to nitrogen and potassium. Moreover, inorganic form of phosphorus becomes unavailable as insoluble ferric as well as aluminium and calcium phosphates under acidic and alkaline condition respectively. A productive soil must have above 30 mg/l of available phosphorus. Sediments of most of the Indian reservoirs and beels are poor in available phosphorus.

Potassium

Potassium helps in the formation of protein, chlorophyll and in stimulating the growth of aquatic plants. Compared to nitrogen and phosphorus, the importance of potassium in aquatic production is less recognised due to its low requirement. Potassium usually occurs in greater concentration in soils and only a fraction of 1-2% remain in easily available form. The available form exhibits equilibrium with relatively unavailable and slowly available form comprising 90-98% and 1-10% of the total potassium respectively. Further, the readily available potassium remain in soil solution and in exchangeable form. The exchangeable form remains adsorbed on soil colloids and the soluble form in the soil solution maintain a dynamic equilibrium. Removal of one form or the other, causes restoration of the equilibrium with the conversion of one form to another. In general, potassium availability is sufficient in Indian soil as well as water, but soils of floodplain wetlands may be deficient in available K due to the presence of dense macrovegetation.

Calcium, magnesium and sulphur

Calcium, magnesium and sulphur are termed as the secondary nutrients in aquaculture. Calcium is an integral part of plant tissues. Sulphur is an essential constituent of protoplasm. The concentration of CO_2 in water is influenced by Ca and Mg. Calcium also acts to increase the availability of other ions in water and in general ameliorates the chemical conditions of water. Calcium is generally present in soil as calcium carbonate. The amount of exchangeable phosphorus in the sediment is inversely related to the calcium carbonate- organic matter ratio so that in highly organic soil with low calcium soluble phosphorus remain adsorbed in exchangeable forms and when sediment is very low in organic matter and high in calcium, phosphorus is fixed as insoluble precipitate. In floodplain wetlands, large amount of Ca, Mg and sulphur are added with the floodwater. Therefore, availability of these elements are more in floodplain wetlands than in upland soils.

Micronutrients

Micronutrients are essential for healthy growth of phytoplankton. But presence of excess amount of some micronutrients may directly or indirectly affect the growth of fish food organisms. Availability of other nutrient elements is also influenced to a great extent by micronutrients. Since floodwater washings of catchments areas and river water enter in reservoir and floodplain wetlands, the amount of some micronutrients may exceed toxic limit. Detailed studies on the micronutrients status in soil and water of aquatic ecosystem are needed.

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ENERGY DYNAMICS AND ESTIMATION OF FISH PRODUCTION POTENTIAL IN SMALL RESERVOIRS

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INTRODUCTION

Reservoirs are characterised by deep waters, existence of lotic and lentic environment and wide seasonal fluctuations in morphometric features. Although small reservoirs provide immense potential for fisheries development the actual fish production from them is not encouraging (about 49 kg/ha/yr; Sugunan, 1995). It is thus essential to have a critical examination of the ecosystem itself and the various factors responsible for its production process. The aboitic habitat variables, chemical constituents and energy dynamics, the transformation of solar energy into chemical energy by producers and flow of this energy through different trophic levels are examined in the present communication.

EVALUATION OF PRODUCTIVITY TRENDS FROM HYDROLOGICAL PARAMETERS

The productivity of any water body is dependent on its water quality parameters. As shown in Table 1, reservoirs vary widely with respect to their water quality. It has been observed that waters with high alkalinity, conductance and dissolved salts are more productive than those with lower values of these parameters (Northcote and Larkin 1956). In general, waters with moderate alkaline pH, high values of alkalinity (> 50 mg/l), conductance(> 200 μmhos), hardness (> 40 mg/l), dissolved organic matter (>1 mg/l), dissolved oxygen (>5 mg/l), nitrate (> 0.5 mg/l) and phosphate (> 0.2 mg/l) are considered to be in the productive range.

PRODUCTIVITY EVALUATIONS FROM KINETICS OF CHEMICAL REACTIONS

From biological point of view, the water column in a reservoir consists of two fundamentally different regions one below the other in which opposing processes take place. These are the regions of photosynthetic production (trophogenic zone) over the region of breakdown (tropholytic zone). In photosynthetic zone carbon dioxide is taken up from bicarbonate by the photosynthetic organisms, resulting in decrease of bicarbonate and increase in carbonate and pH ($2HCO_3 == CO_2 + CO_3 + H_2O$). Oxygen is liberated and it increases in concentration ($6CO_2 + 6H_2O == C_6H_{12}O_6 + 6O_2$). In the tropholytic zone oxygen is consumed, carbon dioxide is liberated, carbonate is converted into bicarbonate ($C_6H_{12}O_6 + 6O_2 == 6CO_2 + 6H_2O$ & $CO_2 + CO_3 + H_2O == 2HCO_3$) and pH increases due to increase in hydrogen ion concentrations ($CO_2 + H_2O == H_2CO_3 == H^+ + HCO_3$). In deep waters like large reservoirs the two zones are separate but in shallow waters like small reservoirs the two zones are not clearly marked. As the intensity of these reactions are directly related to the production and consumption processes, the relative productivity of reservoirs can be evaluated from the magnitude of these variations.

If the rate of reactions in these two zones are high, the reservoirs will show sharp variations in chemical parameters and with the progress of the day (diel variation) and in depth profile during stagnation period (chemical stratification). The dynamics of chemical constituents of impounded waters is reflected by either the phenomenon of chemical stratification or by the intensity of diel variation. In fact, many reservoirs have been classified as low productive, medium productive and high productive based on either the intensity of variations from surface to bottom or the intensity of diel variation in chemical parameters. The most important among the chemical changes is oxygen depletion in the bottom layers of the reservoir brought about by oxidative processes. High photosynthetic oxygen production on the surface (trophogenic zone) and its high consumption in the tropholytic zone cause the klinograde oxygen distribution. Hence oxygen curve gives an important clue for determining the degree of productivity in reservoirs. In shallow waters, the high photosynthetic production results in sharp increase in oxygen with the progress of the day while in night, due to high rate of respiratory consumption dissolved oxygen shows sharp decline. As these two processes are related with the metabolic activities in the ecosystem the diel oxygen curve and its intensity of variation also reflect the relative productivity of the system. Variations in other chemical parameters are also inter-linked and they have also been used for productivity calculation.

ENERGY DYNAMICS OF RESERVOIRS

The energy source for all living organisms on earth is sun. A fraction of the sun's energy (in the form of visible rays) is transformed into chemical energy by producers and stored by them. The energy stored by producers gives the potential energy resource of the systems as this is the available energy which is used by consumers at different trophic levels. In fact all the organisms in the aquatic system are arranged at various trophic levels depending on their mode of obtaining energy and thus for understanding the energy dynamics two types of studies are essential

(i) Transformation of solar energy into chemical energy by producers

(ii) Flow of energy from producers to consumers at different levels

Energy transformation through primary production

The redox process of energy transformation by producers is endergonic in nature requiring more than 100 cal per mole of CO_2 reduced and consequently plants can store large amount of energy in the form of energy rich organic compounds. From the above equation the energy required to liberate one milligram of oxygen through algal photosynthesis is approximately 3.68 calories and hence the amount of oxygen liberated gives a measure of solar energy trapped as chemical energy by producers.

$$\text{The efficiency of energy transformation} = \frac{\text{Energy fixed by producers}}{\text{Solar energy available on water surface}} \times 100$$

The light energy available on the water surface, energy fixed by producers and photosynthetic efficiency of reservoirs have been presented in Table 2. These reservoirs differ considerably both in respect of light energy available and the rate of energy transformation by producers. The available light energy range between 17,20,000 cal/m^2/day (Govindsagar) and 21,50,00 cal/m^2/day(Aliyar) while rate of energy transformation from 3802 cal/m^2/day (Rihand) to 13,580 cal/m^2/day (Aliyar). Thus only 0.202 to 0.743 % of the available light energy is transformed into chemical energy in these reservoirs. Studies made in a number of reservoirs (Natarajan and Pathak, 1987) have shown that the efficiency rarely exceeded 1%. Part of the gross energy fixed by producers is used by them for their own metabolic activities and the remainder is stored by them. Studies in the nine reservoirs have shown that almost 41.7 to 80.3 % of the gross energy was stored by the producers.

EVALUATION OF FISH PRODUCTION POTENTIAL

The productivity potential of any water body depends directly on the efficiency with which producers convert and store light energy into chemical energy, because this is the available energy which flows to other higher trophic level. Odum (1975) and Mann (1969) applied the energy flow approach for calculating the fish production potential of lakes and reservoirs keeping in view that in passing from one trophic level to the other almost 90% of the energy is lost according to the second law of thermodynamics. Odum (1960 & 1962) felt that in lakes and reservoirs which have wide range of fish spectrum belonging to various trophic levels the productivity potential can be taken as 1% of gross or 0.5% of net energy fixed at producer level. Natarajan and Pathak (1983) calculated the fish production potential of a number of reservoirs in the country by taking 0.5% of the net energy fixed by producers as energy available at fish level. The fish production potential estimated on the basis of 0.5% of net producer energy in nine reservoirs studied was in the range of 55.0 kg/ha/yr (Rihand) to 382.5 kg/ha/yr (Gularia). In fact small reservoirs have shown better production potential than large reservoirs except Govindsagar (Table 2). As the small reservoirs provide better scope for management and stock manipulation and also high production potential the fish production from them can be enhanced many fold.

FLOW OF ENERGY FROM PRODUCERS TO CONSUMERS AT VARIOUS LEVELS

The biotic communities in reservoirs are interlinked with one another by energy chains. The complex relationship of food chain and flow of energy in community metabolism are of great importance for formulating policies of stock manipulations. There are two main routes through which energy flows in an aquatic system, one of which has been emphasized much more than the other. The first of these involves grazing of green organisms (producers) by herbivores or plant feeders which are in turn taken by predators, thereby the energy of photosynthesis is transferred to consumers. This is commonly known as grazing food chain. The second path way, which has largely been neglected involves flow of energy from dead organic matter deposited at the bottom through the detrital food chain. The two pathways are shown below.

Energy at first trophic level (Producer level) → herbivores → Predators (grazing chain)

Energy at first trophic level (Producer level) → dead organic matter (Organic detritus) → detritus feeders → Predators (*detritus chain*)

There are a number of restricting conditions for the transfer of energy from primary producers to secondary or tertiary consumers and thus all the energy represented by producers is not always utilized by consumers directly and the unutilized energy reaches the bottom after the death of the organism. This energy is utilized by detritus chain. The pattern of energy utilization in some of the reservoirs have been shown in Table 3.

In small reservoirs, which have been stocked by desired species, 60 to 80% of the energy harvest as fish contributed by primary consumers (mainly by detritivores) and the main path of energy flow is through detritus chain. These reservoirs show better production and energy conversion efficiencies (0.121 to 0.355% from photosynthetic production to fish and 0.00083 to 0.0023%) from light to fish. Although almost 15.6 to 49.6% of the potential is actually harvested from them, still there is further scope for enhancement of fish production (at least to 50%). In case of large reservoirs except Govindsagar which has shown better conversion efficiency (0.2% from photosynthesis to fish or 27.0% of the potential) other two reservoirs have shown negligible efficiencies (0.0007% of photosynthesis or 7.3% of potential). If the water body has the dominance of primary consumers (either herbivores or detritivores) the energy harvest and the conversion efficiencies will be better. This has been proved true in the present observation as the reservoirs, whether small or large, dominated either by herbivores or detritivores have shown better utilization of energy or conversion efficiencies than those which are dominated by single species (Rihand) or tertiary consumers (Nagarjunasagar).

Small reservoirs have shown much higher fish production potential and are well within our control for applying culture-based fisheries principles for enhancement of production. Energy dynamics of small reservoirs provide valuable tools of revaluating production potential and extent of utilization of energy in them. By applying suitable management principles through stock manipulation, the fish production can be increased many fold. The energy dynamics of an ecosystem do take into account the various trophic levels but this approach has one disadvantage that many animals are omnivorous and can not be assigned to a particular level. Moreover, even the feeding habits of the animals do change with the availability of food. Thus, one has to be very cautious while grouping the organisms at various trophic levels for energy dynamics studies.

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Table 1. Water quality of different Indian reservoirs

	Small reservoirs					Large reservoirs			
	Aliyar	Bachhra	Bagla	Naktara	Bhavani sagar	Gularia	Govind sagar	N.sagar	Rihand
Water temperature (O^c)	26.20	26.70	26.70	24.80	25.80	25.80	22.50	27.50	24.00
Transparency (cm)	64.2	66.7	80.0	48.9	107.0	50.2	112.0	260.0	54.0
Dissolved oxygen (mgl^{-1})	7.54	6.82	8.06	9.03	7.50	7.10	8.80	8.00	7.7
pH	8.2	7.9	8.1	7.8	8.3	7.6	8.8	8.3	7.7
Free Co_2(mgl^{-1})	Nil	1.3	1.27	1.25	Nil	2.35	Nil	Nil	4.80
Total alkalinity (mgl^{-1})	60.2	127.7	60.6	56.6	52.1	53.6	69.3	110.0	43.8
Sp.conductivity (µmhos)	259.4	236.52	121.2	121.3	268.9	118.0	215.0	450.0	97.7
Total dissolved solids (mgl^{-1})	130.0	118.25	60.4	61.0	135.0	59.8	108.0	232.0	49.2
Total hardness (mgl^{-1})	72.8	37.6	48.1	41.4	50.9	39.28	54.8	102.0	48.0
Dissolved organic matter (mgl^{-1})	0.88	0.68	0.82	0.68	1.2	0.92	0.48	0.98	0.42
Silicate (mgl^{-1})	9.5	10.04	3.30	5.20	9.90	12.0	1.10	30.0	6.40
Nitrate (mgl^{-1})	0.28	0.13	0.31	0.24	0.20	0.14	0.20	0.70	0.40
Phosphate (mgl^{-1})	0.06	0.14	0.30	0.24	0.02	0.12	0.02	0.01	0.08

Table 2. Energy transformation through Primary production and fish Production potential in different Indian reservoir

Reservoirs	Solar energy penetrating water surface (calm^{-2}day^{-1})	Energy fixed by producers (calm^{-2}day^{-1})	Photo synthetic efficiency (%)	Net energy assimilated (calm^{-2}day^{-1})	Energy lost as respiration (calm^{-2}day^{-1})	Ratio of nergy assimilated to gross (%)	Fish production potential (Kg ha^{-1}yr^{-1})
Aliyar	21,50,000	13,580	0.58	8370	5210	61.6	289.7
Bhavanisagar	21,30,000	8,781	0.412	4610	4171	52.5	159.6
Bachhra	18,67,000	9,547	0.512	7669	1878	80.3	273.3
Bagla	18,67,000	13,870	0.743	9,238	4632	66.7	329.4
Naktara	18,92,000	12,490	0.66	7742	4748	62.0	276.0
Gularia	18,67,000	13,056	0.699	10,735	2321	82.2	382.5
Govindsagar	17,20,000	11,696	0.682	7626	4070	65.2	264.0
Nagarjunasagar	20,50,000	5959	0.290	3450	2509	57.9	120.0
Rihand	18,83,760	3802	0.202	1586	2216	41.7	55.0

Table 3. Photo synthetic energy fixation and energy conservation in different Indian reservoirs

Ecosystems	Visible radiant energy Kcalha^{-1} yr^{-1} x 10^6	Autofrophic energy fixed by producers Kcalha^{-1} yr^{-1} x 10^4	Contribtion of fishes at different trophic levels (Kcalha^{-1} yr^{-1})				Total energy harvest as fish	Conversion of energy		
			Major primary consumers		Major secondary consumers	Major tertiary consumers		Photo synthesis to fish (%)	Light to fish (%)	Potential to actual harvest (%)
			Herbivores	Detritivores						
SMALL RESERVOIR										
Aliyar	7847	4937	4344	48,528	9912	2592	65376	0.132	0.00083	18.8
Bhavani sagar	7775	3204	24860	40,200	6480	20640	95,000	0.29	0.001	49.6
Bachhra	6825	3486	29,520	43,560	13,800	36,960	1,23,840	0.355	0.00182	37.8
Bagla	6825	5063	12,396	23,565	10,678	14,730	61,368	0.121	0.0009	15.6
Naktara	6906	4559	51,517	77,554	27,554	3206	1,60,200	0.351	0.0023	48.1
LARGE RESERVOIR										
Govind sagar	6278	4270	49,080	9840	24,840	170	85680	0.20	0.0013	27.0
Nagarjuna sagar	7480	2175	1545	645	4125	4725	12,000	0.055	0.00016	8.3
Rihand	6875	1390	4320	-	4.80	-	4800	0.034	0.00007	7.3

METHODS OF EVALUATING PRIMARY PRODUCTION 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 organisms such as phytoplankton, periphyton, algae and 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 carbondioxide in the surrounding waters. Rates of photosynthesis 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. Hence, phytoplankton 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 exist but decreases in lower layers where overshading by the plankton reduces light penetration (Hepter, 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 photosynthetic rates. The primary productivity in oxbow lakes (*beels*) may be quite different from that of pond ecosystem. The *beel* ecosystem generally contains large amount of submerged aquatic weeds, so greater photosynthetic rates and oxygen concentrations are noted.

FACTORS REGULATING PRIMARY PRODUCTION

Factors regulating the magnitude, seasonal pattern and species composition in phytoplankton photosynthesis are light, temperature, nutrients, physical transport process and herbivority. Conducive radiation or light in the wave length range of 400-700 nm is the 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. Maximum photosynthesis is noted just below the surface. Rate of photosynthesis diminishes at higher depths due to poor light availability. However, at very high intensity of light, photosynthesis can be adversely affected 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 lakes 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 requires N, P, Si, Mo, Zn, Mn, Ca, CO_2 and vitamins for their growth and sustenance. The most important are the macronutrients (C, N, P and Si). Phytoplankton growth and photosynthesis are, in general, congenial in the temperature range of 20 to 25^0 C. Above 30^0 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 dissolved oxygen (DO) 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 can also be determined with an oxygen probe.

5) Suspend the light and dark bottles at the depths 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 Winkler method or by an oxygen probe.

Calculation

$$\text{Gross Production } (mgC/m^3/hr) = \frac{LB\text{-}DB}{T} \times \frac{12}{32} \times \frac{1000}{PQ}$$

$$= \frac{LB\text{-}DB}{T} \times 312.5$$

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

where LB = Oxygen in mg/l in the light bottle, IB = Oxygen in mg/l in initial bottle and T = Time in hours.

PQ = Photosynthetic coefficient = 1.2

$$\text{Respiration} = \frac{IB\text{-}DB}{T} \times 375$$

DB = Oxygen in mg/l in dark bottle

Primary productivity is generally reported in grams carbon fixed per m^2/day. Estimate the productivity of a vertical column of water (1 meter 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, the data can be adjusted 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 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 continuously 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 technique) 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 sulphur bacteria, purple sulphur bacteria, *etc*. absorb CO_2 and produce carbohydrate in presence of light but in this case photosynthesis oxygen is not evolved. In such cases ^{14}C method in very effective.

The overall reaction is as follows :

$$6CO_2 + 12H_2S \xrightarrow[\text{709 K. Cal (purple sulphur bacteria)}]{\text{light}} C_6H_{12}O_6 + 6\,H_2O + 12S$$

Similarly,

$$6CO_2 + 15H_2S \xrightarrow[\text{709 K. Cal (green sulphur bacteria)}]{\text{light}} C_6H_{12}O_6 + 6\,H_2O + 6\,NaHSO_4$$

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 quantity (5 μ Ci ^{14}C/ml) of sodium bicarbonate containing ^{14}C is added to each bottle. The bottles are then sealed and suspended in water *in situ* for a duration of 3-4 hours. If temperature and illumination at the sampling depth 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/l), Dioxane (400 ml/l), Ethyl alcohal (200 ml/l), Phenyl phenyl oxazole (2.5 g/l) and Phenyl oxaxolyl phenyl oxazolyl benzene (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

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

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 $= A + 0.44\,(2B + C) + D = E$

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

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
Efficiancy of the counter X_7 = appox. 40%

Then Net primary production =

$$\frac{(X_1 - X_2) \times \frac{X_3}{X_4} \times 1.064 \times 100 \times F}{X_5 \times X_6 \times X_7} \text{ mgC/m}^3\text{/hr}$$

Here 1.064 is a correction 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.

The oxygen method cannot give reliable information about the bacterial photosynthesis where oxygen is not involved. 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 studied (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.*, 1998). The floodplain lakes of Ganga and Brahmaputra basins have 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 beels, 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, according to Ganapati (1972) and Sreenivasan (1972) 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^3/day.

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CHEMICAL INDICATORS OF PRODUCTIVITY IN SMALL WATER BODIES

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INTRODUCTION

Although a precise and universally acceptable definition of small water bodies (SWB) is yet to made, Anderson (1989) included in it the small reservoirs and lakes less than 10 Km^2, small ponds, irrigation canals, floodplain wetlands and small rivers and streams less than 100 km in length.

Most of the wetlands of India are located on floodplains of major rivers forming a potentially rich inland fishery resource known as "floodplain wetlands". Mainly distributed in Assam, West Bengal, Bihar, Manipur and Arunachal Pradesh, they are locally called *beels*, *jheel*s, *maun*s, *chaur*s and *pat*s. At times, it is very difficult to establish their identity owing to man-made modifications to their environment. *Bheri*es, the estuarine wetlands associated with the lower reaches of Hooghly and Matlah rivers are also very rich in nutrients as they receive tidal water. The floodplain wetlands are extremely rich in nutrients being reflected by rich organic carbon and high levels of available nitrogen and phosphorus in the soil regime reflecting in higher biological productivity offering tremendous scope for augmenting culture and capture fisheries. Unfortunately, these wetlands are not given due importance in increasing fish production and they remain under severe threat of eco-degradation due to extensive irrigation and flood control activities, siltation and habitat destruction. The problem is further aggravated with heavy infestation of macrophytes restricting availability of dissolved nutrients in water phase for plankton production. Other small water bodies include irrigation canals, small rivers and streams less than 100 km length, basically meant for capture fisheries.

A sound knowledge of chemical processes involved in the production process is of utmost importance to set management norms for the aquatic environment. The basic objective of such study is to know the physical and chemical reactions taking place in the aquatic environment with the interactions with the biotic communities both individually or synergetically. Several chemical reactions are also involved in the availability of nutrients in water in optimum quantities to the fish food organisms.

PHYSICAL INDICATORS OF PRODUCTIVITY

A study of nature and properties of basin soil is of immense help in determining the productivity wherein a series of physical, chemical, biochemical and microbical reactions are taking place constantly rendering release of nutrients into the water phase. Particle size distribution is the most important physical factor governing retention of water. A distinct, colloidal, loosely stratified organic layer followed by a clayey mineral layer of varying composition is best suited for productivity. The basin soil of Aliyar reservoir in Tamil Nadu comprising 24 % sand, 29 % silt and 47 % clay represents a moderate to high productive nature of soil. Like many other small reservoirs, Manchanbele reservoir of Karnataka also had a sandy-clay nature of soil (70 – 77% sand, 10 –12% silt and 14 – 20% clay) due to poor fertility status in the catchment. In contrast, the floodplain wetlands have lower percentage of sand content in their basin soil. Bhomra and Haripur (open) *beels* of West Bengal have sand-silt-clay contents (%) of 65, 21, 14 and 50, 11, 39 respectively. Mechanically, the bottom soil should not be so adsorptive as to eliminate most of the nutrients from water phase and at the same time it must not be so porous to allow excess loss of nutrients and water. Small water bodies with sandy basin can be reclaimed with the application of farm yard manure @ 10 t/ha to reduce the porosity of soil facilitating in forming a thick organic layer followed by a thick loam to clay-loam layer for economic utilization of the nutrients.

Ambient *water temperature*, one of the most important physical factors determining productivity, influences the rate of activity from a molecular to an organismal scale. Water temperature depends on sunlight, climate, depth and transparency of water. In tropical small water bodies, temperature is not a limiting factor and the diurnal variation of water temperature ranges from 2-4°C (post-monsoon) and 10-12°C (pre-monsoon). In most occasions temperature exerts influence on plankton dynamics and availability of nutrients from soil to water phase. Wide fluctuation in summer temperature does not pose any direct adverse effect on fish. But at times, in water bodies with high organic content in soil, large scale fish mortality takes place as the surface water gets cooled suddenly by a rain shower or a cold breeze. Production (P)/mean biomass (B) is believed to rise with temperature on a linear or curvilinear scale. Apart from accentuating primary production, the general positive effect of temperature on secondary production is its impact on reproductive biology of organisms. Increase in temperature also leads to accelerating growth and feeding rate with the decrease in egg development period in animals rendering their increased productivity. Probst (1950) found an average increase in carp yield of 22 kg/ha for 1°C rise of temperature. Tropical small water bodies with higher heat budget have greater fish yield potential than their temperate counterparts. Its effect on small water bodies is more pronounced due to extended euphotic zone with more penetration of sunlight.

This facilitates increased rate of biochemical and microbial activities with the release of more available nutrients to water phase by decomposition of organic matter of bottom sediment.

Sunlight, the prime physical factor of primary production, the very basis of carbohydrate production in aquatic ecosystem greatly influences productivity. Penetration of light to water phase depends on turbidity which in turn depends on suspension of clay micelles, particulate organic matter, pigmentation derived through decomposition of organic matters or dispersion of plankton. Turbidity due to colloidal micelles (organic and inorganic) is of paramount importance in holding nutrient ions adsorbed/absorbed on their electrically charged extensive surface, maintaining equilibrium concentration of these ions in water phase. So, productive water should be a little bit turbid. In general, in small water bodies, transparency of water becomes low during monsoon due to inflow getting stabilised subsequently during post-monsoon months. Turbidity is considered to be a limiting factor in plankton productivity in small water bodies (Benson and Cowell, 1967). Highly turbid water is undesirable for fish culture.

CHEMICAL INDICATORS OF PRODUCTIVITY

(Table 1 & 2)

Water reaction (pH)

Fish grow well usually in alkaline waters (pH 7.0-8.0). pH above 10.8 or below 4.8 is reported to have detrimental effect (Ohle, 1938). Reproduction and growth of fishes will diminish at pH <6.5 or > 9.5 (Swingle, 1961; Mount, 1973). According to Banerjee (1967), water with near neutral reaction with pH 6.5-7.5 is best suited for fish ponds. Due to strong buffering capacity offered by CO_2-HCO_3- CO_3 system, small water bodies in India seldom show acidic water reaction. The exceptions are some of the floodplain wetlands of North Bengal (Bhaluka, Nehali) and Midnapur district (Sarasanka beel) of West Bengal. These *beel*s show acidic reaction of water due to poor buffering capacity as influenced by higher concentration of free CO_2 in water and poor free $CaCO_3$ in soil. It was also observed that phytoplankton primary production was in the range of 200 to 432 mgC/m^3/h in some ponds of Jalpaiguri district with acidic soil reaction (soil pH 5.8-6.2) while in some ponds in Malda district having neutral soil reaction (soil pH 6.9-7.2), the production was significantly high (526 to 762 mg C/m^3/h) (Nath *et al*, 1986; Nath & Tripathi, 1997). Same was true in case of floodplain wetlands, where primary production in *beels* of North Bengal with acidic soil reaction was much lower than that of South Bengal. Low production in such water bodies with acidic sediment is primarily because of non-availability of nutrients in water phase due to fixation of nutrient ions by clay particles as well as rich organic matters. In general, water reaction is low during monsoon due to dilution of alkaline substances or dissolution of atmospheric CO_2. It is a limiting factor in most of the small water bodies of India which can be corrected by adopting suitable chemical measures.

Specific conductivity

Measurement of specific conductivity, an index of dissolved solids, indicating the total concentration of soluble ions is a very good indicator of productivity. It also gives an indication of state of mineralization in any aquatic ecosystem. Its value ranges from 25-500 μmhos/cm and the optimum limit for high productivity is around 200 μmhos/cm or more. In sediment also, it does not necessarily attain high values (unless polluted extremely) so as to affect fish productivity. As the changes in electrical conductivity are associated with the release or depletion of soluble ions in the soil water interphase, it has a definite indirect role to play in aquatic productivity. Conductivity also provides a useful estimate of salinity/chlorinity in freshwater. In normal freshwater, chloride content is within 10 to 30 mg/l and the values higher than this indicate pollution.

Total alkalinity

Total alkalinity (TA) is basically caused by the carbonates and bicarbonates of calcium and magnesium being expressed as mg/l of equivalent calcium carbonate. Along with these, dissolved CO_2 in water forms an equilibrium system and is of prime importance in determining productivity of small water bodies. Freshwaters, having total alkalinity of 40 mg/l or more are productive (Moyle, 1945). This greater productivity is attributed to phosphorus and other nutrients that increase along with total alkalinity (Moyle, 1946). Banerjee (1967), while determining productivity of a number of ponds also opined that TA below 20 mg/l was definitely indicative of low production. However, in fertilized ponds with TA ranging from 0-20 mg/l, fish production tends to increase with increasing alkalinity. Ponds with TA of 200-300 mg/l have been successfully used for pisciculture. It was also noticed that the low fish production in the *beels* Bhaluka (South Dinajpur) and Sarasanka (Midnapur) was due to low TA values ranging between 14-20 mg/l. However, there are instances of low carbon dioxide in lakes with high calcium carbonate contents in sediment of catchment, resulting in low productivity (Wetzel, 1975).

Total hardness

Total hardness (TH) refers to the concentration of divalent metal ions in water expressed as equivalent of $CaCO_3$ which is usually related to TA as the anions of alkalinity and cations of hardness are normally derived from the solution of carbonate minerals. Ecosystems having moderately hard (61-120 mg/l) to hard (120-180 mg/l) water are more productive as the total hardness reflects the trends of Ca and Mg in water bodies. In most occasions, TA of water exceeds corresponding TH values due to association of bicarbonate and carbonate with Na & K rather than Ca & Mg. But most of the ponds in arid zone have higher TH compared to their respective TA values as concentration of ions by evaporation may result in precipitation of ions responsible for alkalinity. Toxicity of some heavy metals to fish is immensely reduced in water having high pH and TH values owing to formation of carbonates. In small water bodies where TA falls below 15 mg/l, the water develops low buffering capacity. Very high alkalinity (200-250 mg/l), coupled with low TH (<20 mg/l) results in the rise in pH during afternoon causing fish kill. A small amount of Ca and Mg is necessary for productive waters and the required quantities are mostly present if TH is above 20 mg/l. Mg is a component of chlorophyll and at times it acts as a carrier of phosphate and stimulates bacterial reduction of organic matters.

Dissolved gases

Dissolved oxygen (DO) is a critical factor in natural waters both as regulator of metabolic processes of plant and animal communities and as an indicator of water quality. It is not a limiting factor in most of the small reservoirs. But the dynamics of DO in fish ponds and weed choked floodplain wetlands is very complex. In some macrophyte dominated *beels* of West Bengal, a poor concentration of DO was noticed (1.2 to 3.6 mg/l) during monsoon due to its rapid consumption by bacteria for decomposition of bottom organic load. Wide diel fluctuations in DO occurring typically in some fish ponds and *beels* have a detrimental effect on fish health. The minimum tolerable concentration of DO for fish is a function of exposure time, species, size, physiology, dissolved solutes, *etc*. As stated by McKee and Wolf (1962), DO for warmwater fish habitats shall be not less than 5 mg/l during at least 16 h of any 24 h period. So, a good productive water should have DO concentration more than 5 mg/l.

Concentration of free CO_2 both in surface and sub-surface waters is a good indicator of productivity. CO_2 is highly soluble in water but is a minor constituent of the atmosphere and remains present in equilibrium concentration by giving an acidic reaction in water. In shallow waters, its presence is noticed in monsoon due to rain and generally present year round at the bottom with high content specially in summer during the active phase of degradation of organic load. Its presence is essential for photosynthesis either in the form of CO_2, HCO_3 or CO_3 and its degree of concentration at the bottom is an important determinant of biogenic productivity which is more phenomenal in tropical small reservoirs and other small water bodies.

Dynamics of nutrients

The effective functioning of any aquatic ecosystem depends on the circulation of nutrients which takes place in most of the occasions at a faster rate in shallow small tropical water bodies. Nutrients enter into the aquatic system through allochthonous inputs especially in small reservoirs having extended fertile catchment area in addition to their autochthonous resources. In pond ecosystem, it is compensated basically through fertilisers and in open *beels* it is replenished to some extent through allochthonous inputs carried by riverine inflow in addition to authothonous sources. Among nutrients, the role of nitrogen and phosphorus in aquatic productivity have been recognised.

Nitrogen

Nitrogen, a major constituent of protein occupies a predominant place in aquatic system. Nitrogen is basically present in soil in organic form, gradually getting mineralised to ammonium and nitrate forms thus making its availability to fish food organisms. Out of the NH_4^+ ions some are i) adsorbed by soil colloidal complex ii) released to water phase being utilized by plankters as NH_4^+ or as NO_3^- forms and iii) lost through volatilization when associated with high pH and temperature. The nitrate ion, being the readily available form of nitrogen to phytoplankters is highly soluble in water as well as diffusive in nature. However, low supply of soil-N to water phase could be considerably compensated by ultimate supply of nitrogen through fixation by azotobacter, blue green algae, atmospheric electrical discharge and photochemical fixation. Interactions of top-down (grazing) and bottom-up (nutrient supply) control in planktonic nitrogen cycling is of paramount importance in aquatic productivity for higher growth of fish. Grazing and N-recycling are intricately connected. The presence of large zooplankton community simultaneously provides top-down control of biomass and bottom-up nutrient supply. It is stated that, as much as 50% of the total-N required by phytoplankton was provided through zooplankton excretion alone (Harris, 1959).

A water body having medium to high productive potential requires 25-75 mg available -N per 100g of soil. Dissolved inorganic nitrogen in the range 200-500 µg/l may be considered favourable to fish productivity. Fertilization coupled with liming provide required amount of nitrogen to fish food organisms in fish ponds where intensive culture of fish is practised. In *beel* ecosystem, practice of liming on regular basis annually @ 400-500 kg/ha would release organically bound-N into water phase from bottom detritus load. Un-ionised NH_3 and NO_2^- forms are toxic to fish if their concentrations exceed 25 & 1,000 µg/l respectively. In Indian reservoirs, available - N in water is very low in most part of the year except in monsoon and summer.

Phosphorus

Though, a relatively minor constituent, phosphorus is often considered to be the most critical single element in maintaining aquatic productivity. It helps in assimilation of nitrogen into cellular matter. The role of phosphorus as a limiting factor in the production of algae in natural lakes is diverse and complicated (Welch, 1952). Its importance is very much felt due to its lesser availability in Indian waters. Inorganic-P is very reactive, forming sparingly soluble iron and aluminium compounds in acid soil and insoluble calcium phosphate in alkaline soil thus restricting its release from soil to water phase under both extremities of pH. Available phosphorus (mg/100 g of soil) should be in the range of 4.7 to 6.2 for moderate to high productivity in soil but is of low order in some small reservoirs studied. Thus, in most of the Indian reservoirs except for a shorter period during monsoon, availability of phosphate is of very low order and rarely exceeds 100 µg/l. In pond ecosystem, it is substantiated through inorganic phosphatic fertilisers along with application of lime to increase filterable orthophosphate by 100 to 500 µg/l. Lack of these nutrients in reservoir ecosystem does not seem to be indicative of low productivity because of their rapid turn over and quick recycling, 95% of the phosphorus is taken up by phytoplankton within 20 minutes (Hayes and Phillips, 1958).

Potassium

Potassium, the third major nutrient in maintaining aquatic productivity has not been emphasised so far due to its easy and optimal availability in soil as well as in water under the Indian context. Bottom sediment is productive in reservoirs having moderate pH and base saturation helps in maintaining a high level of potassium. Liming can be done fruitfully in small reservoirs, to enhance potassium availability in soil through cation exchange. In tropical reservoirs release of potassium takes place during dry summer which increases potassium status during subsequent monsoon months.

Silicate

In natural waters, silicon remains in silicate form which is reactable. Normally, 1-30 mg/l or more of silicate silicon is present in natural fresh waters. At high temperature and pH, the solubility of silicate greatly increases. As silica has been the integral structural constituent of diatoms and many cases it is able to regulate their growth. The assimilation of silica and subsequent precipitation by diatoms have been forming the greatest sink of silica in water.

Micro-nutrients

Very limited attention has been given so far to micro-nutrients which are of great significance in improving aquatic productivity inspite of their requirements in very small amounts. They influence the availability and uptake of other nutrients in aquatic system. Bottom sediment of fine texture with rich organic matter content can retain larger amount of micro nutrient cations in the exchange phase.

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Table 1. Water quality of some small reservoirs in India

Reservoirs (Area in ha)	pH	Sp.Cond (µS/cm)	TA (mg/l)	TH (mg/l)	Cl^- (mg/l)	NO_3-N (µg/l)	PO_4-P (µg/l)	SiO_2-Si (mg/l)
Amaravathy (850)	6.7-9.1	38-63	7-84	18-50	0.4-1.0	Tr	Tr-10	1.4-38.5
Aliyar (320)	6.6-8.8	39-110	16-58	12-44	10-12	Tr-40	Tr-20	2.8-24
Thirumurthy (388)	7.2-7.6	25-38	20-22	10-15	10-12	-	-	-
Manchanbele (329)	7.2-8.6	300-490	96-180	68-86	19-38	1-54	1-280	2.0-22.8
Nelligudda (80)	7.2-9.2	196-453	70-160	60-100	19-34	Tr-240	10-110	3.0-12.0
Gulariya (300)	7.2-8.4	-	38-80	13-34	-	80-200	50-130	5-14
Bachhra (140)	7.0-8.3	149-300	95-190	21-80	14-30	85-180	60-250	6.8-14.0
Baghla (250)	7.3-8.8	63-292	42-106	35-90	14-34	280-330	280-360	2.4-4.9
Nalkari (992)	7.8-8.3	100-120	48-55	40-45	14-19	Tr-70	Tr-60	9.0
Sarni (1012)	6.8-7.7	133-350	62-94	52-53	14-20	10-272	10-70	2.5-6.3
Namana (528)	8.5	379-473	16-58	12-40	8-16	Tr-110	154-163	4.3-17.0
Chapparwara (200)	8.0-8.4	-	76-100	-	-	400-1100	110-160	1.9-8.0

Table 2. Sediment characteristics of some small reservoirs in India

Reservoirs	pH	E.C.ms/cm	Organic carbon (%)	Total nitrogen (%)	C/N	Available nitrogen (mg/100 g)	Available-P (mg/100 g)
Thirumurthy	6.5-7.9	0.17-4.0	0.28-3.7	-	-	44.0-47.6	0.22-0.40
Aliyar	6.42	-	0.82	0.06	13.9	29.2	3.30
Sarni	5.96-6.94	-	1.05-1.51	0.11-0.19	6-13	40-43	Tr-2.2
Manchanabele	4.59-4.96	0.9-1.34	1.76-1.81	0.12-0.32	6-15	50.4-89.6	0.73-0.98
Kyrdemkulai	5.9-7.6	0.087-0.12	0.29-1.63	-	-	7.7-32.33	0.59-1.12

Summer School on
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BIOTIC COMMUNITIES IN SMALL RESERVOIR FISHERIES WITH SPECIAL REFERENCE TO PLANKTON AND BENTHOS

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INTRODUCTION

Scientific advice on fisheries management developed at CIFRI for the small reservoirs, which contribute more than 50% of the total area under this resource, has attracted the attention of scientists and developmental authorities alike, as it provides opportunity to increase the inland fish production in the country in reasonably short time and without much of input cost. Such water bodies are easy to handle and a quantum jump in fish production is possible following the principle of culture-based-fisheries, where stocking remains the mainstay. However, to achieve enhancement in fish production on sustainable basis, a thorough understanding of various ecological facets, especially the nuances of natural food for fishes are essential.

BIOTIC COMMUNITIES

The reservoirs are complex biotopes, significantly different from lakes, owing to relatively higher ratio of drainage area of the basin to water surface area as compared to lakes of similar size. Accordingly, the seasonal and yearly flow of water into the reservoirs is relatively higher. Reservoirs tend to lose nutrients, than accumulate and recycle them through biotic communities as in natural lakes. The initial flux of nutrients due to drainage of water from larger catchments is eventually flushed out and lost to river down stream. Thus, instead of building higher nutrient levels through time as in lakes, it declines to settle at a lower level. This singular characteristic of reservoirs has great bearing in shaping the biotic communities, which is less stable as well as relatively lower in community size, except plankton, as compared to natural lakes. The diversity of biotic communities is, however, large owing to distinct micro habitat diversifications like *littoral*, *sub-littoral* and *profundal*. In addition to this, the texture of biotic communities in reservoirs vary according to riverine, lucustrine and intermediary characteristics.

Plankton

Plankton is a heterogeneous assemblage of microscopic organisms, primary producers and primary consumers, which complete their life cycle in suspended media and are dependent on waves and currents for movement. Obviously, the plankton assemblage comprises two distinct components *viz.* phytoplankton and zooplankton. Plankton populations can also be classified based on their habit and size such as euplankton (true plankton), tychoplankton (plankton associates like filamentous algae), net-plankton (> 40 µ), nannoplankton (< 40 µ and > 10 µ), piccoplankton (< 10 µ) and so on.

The abundance and fluctuation of phytoplankton is a function of nutrient concentration in an ecosystem, which lays the foundation of aquatic productivity. In addition to nutrients the abundance and texture of phytoplankton community is regulated by a number of other factors like light, grazing pressure, turbulence and turbidity. Further, the total number of phytoplankton is usually characterized or expressed as the number of cells, the volume of cell count, the amount of chlorophyll-*a* or ash free dry weight of algal biomass. Of these chlorophyll-*a* concentration has greater acceptance among the limnologists because it can be measured with ease and it covers both net and nannoplankton. Regression models of phytoplankton can be successfully employed to understand the productivity pattern of phytoplankton. Though chlorophyll-*a* content varies with species and condition under which they exist (Heyman and Lundgren, 1988), but on an average it ranges between 1 and 2% of their dry weight (Reynold, 1984). The phosphorus content of algae varies between 0.4 and 1% of the dry weight in reasonably enriched ecosystem (Ahlgren, *et al.* 1988), while their nitrogen content is usually about a factor 10 higher phosphorus (Smith, 1982). The growth and abundance of phytoplankton depend on a number of ecological variables.

Zooplankton

The zooplankton assemblage in reservoir ecosystem comprises mainly of Protozoa, Rotifera, Cladocera and Copepoda. However, coelenterates, flatworms, gastrotrichs, mites and larval insects are also present at times. Each group of animals exhibits different sets of life cycle leading to a well-defined periodicity and annual succession. As in case of phytoplankton the community, structure of zooplankton is being regulated by a number of factors.

- The Rotifers share with Cladocera and Copepoda, the major part in the limnoplankton.
- The nature of chemical limitations acting on zooplankton remains unexplored.
- Horizontal and vertical migration among zooplankton is common.

- The grazers exert considerable control on zooplankton associations. In general, where fish are in abundance larger species of zooplankton are at disadvantage.
- The rotifers tend to increase in such water bodies where grazing pressure is relatively higher.

Benthos

Benthos are referred to the organisms that are attached to, crawling on, or burrowed into the bottom substrates (sediment, debris, logs, macrophytes, *etc*) at least during a part of their life cycle. A typical grab sample from lake bed might produce benthos *viz;* oligochaetes, nematodes mollusc, crustraceans, insects, *etc.*

Being the dominant group in the food chain, the benthos are important organisms in the productivity chain in reservoir fisheries.

Heptabenthos cover (Periphyton)

Organisms growing at the solid-liquid interface are the important biocenose in reservoirs, lakes and rivers (Jha, 1979). Such organisms are known by different terminologies, designated by different workers, like *Rhizobenthos* (rooted vegetations), *Herpobenthos* (organisms growing at sediment), *Haptobenthos* (organisms adanate to solid substrates) and *Endobenthos* (organisms boring the solid substrates). *Nereiden* (assemblage of at the basal parts of boats), *Aufuch* and *Lasion* were also the terms used to denote biological covers by earlier workers. Behning (1924) for the first time used the terminology periphyton for the plants growing over boats. Recently, however, Round (1985) preferred to use *epipellic* (organisms growing over pebbles or sediments), *epilithic* (organisms growing over solid substrata) and *epiphytic* (organisms growing over macrophytes or filamentous algae).

The diatoms as a group, being merobenthic in origin, generally, dominates and regulates the community size of biological covers (Jha, 1979, Sugunan and Pathak, 1986). The stratified assemblage of biota under biological covers generally depicts the following sequences:

(i) Bacillariophyceae > Chlorophyceae > Myxophyceae > Euglenophyceae > Animalcules (protozoa + rotifers)- (*Normal water quality*).

(ii) Bacillariophyceae > Myxophyceae > Euglenoids > Chlorophyceae > Animalcules-(*Enriched water quality*).

Nekton

The nekton is the part of the biotic community, which exhibits faster locomotive powers and determines its own distribution. In inland water fishes and prawns are the best examples of nekton. A number of insects like diving beetles or hemipterids (water-boatmen) are the other organisms under nekton, but their distribution is restricted mainly to the vegetation-covered, shallow marginal areas of the lakes. The only true pelagic insect is phantom larva, *chaoborus*, but due to its small size, it is forced to depend at the mercy of the water currents. The fish diversity in Indian reservoirs is given in Table 1.

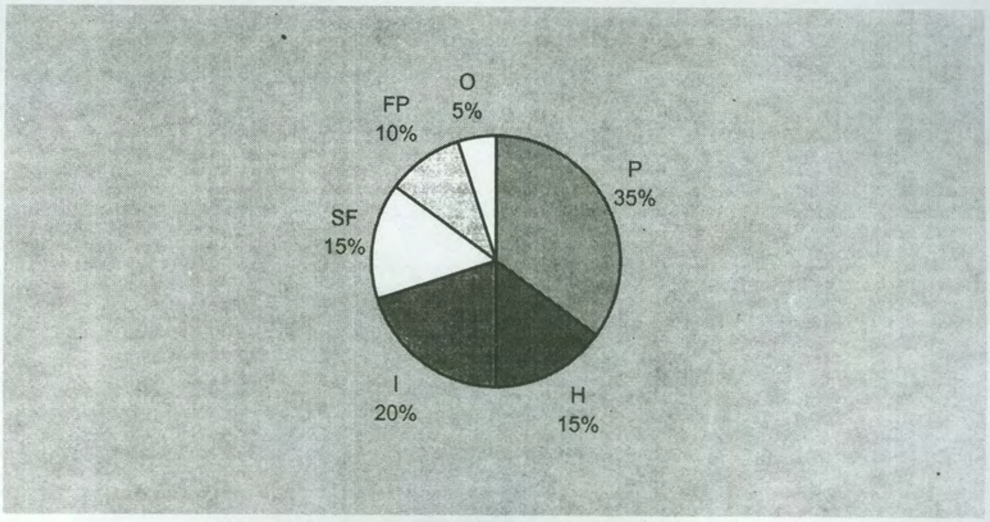
Table 1. Diversity of fish fauna in Indian reservoirs (Sugunan, 1995)

Broad Groups	Species
The Indian Major Carps	*Labeo rohita, L. calbasu, L. fimbriatus, Cirrhinus mrigala, Catla catla*
The mahaseers	*Tor tor, T. putitora, T. kudree, Acrossocheilus hexagonolepis*
The minor carp, Indo-Gangetic region	*Cirrhinus reba, Labeo kontius, L.bata, Puntius sarana, P. dubius, P. kolus, Chargunius chagunio*
The minor carp, Peninsular India	*Cirrhinus cirrhosa, Puntius carnaticus, P. dobsonii, Thynnichuthys sandkhol, Osteobrama vigorsii*
Snow trout	*Schizothorax plagiostomus*
Large catfish	*Aorichthys aor, A. seenghala, Wallago attu, Pangasius pangasius, Silondia silondia, S. childrenii*
Airbreathing catfish	*Heteropneustes fossilis, Clarias batrachus*
Feather-backs	*Notopterus notopterus, N. chitala*
Murrels	*Channa marulius, C. striatus, C. punctatus, C. gachua*
Forage fish	*Ambassis nama, A. ranga, Esomus dandrica, Aspidoparia morar, Amblypharyngodon mola, Puntius sophore, P. ticto, P. punjabensis, Oxygaster bacaila, Chela laubuca, Barilius barila, B. bola, Osteobrama cotio, Gudusia chapra, Setipinna phasa, Chela chela, Botia lohachata, Garra gotyla, Rhinomugil corsula*
Exotic fish	*Oreochromis mossambicus, Hypophthalmichthys molitrix, Cyprinus carpio specularis, C. carpio communis, Gambusia affinis, Ctenopharyngodon idella*

The general distribution pattern of fish biomass in small reservoirs is shown in Fig. 1 and 2.

Fig. 1: Natural stock of fish in reservoirs (without external stocking)

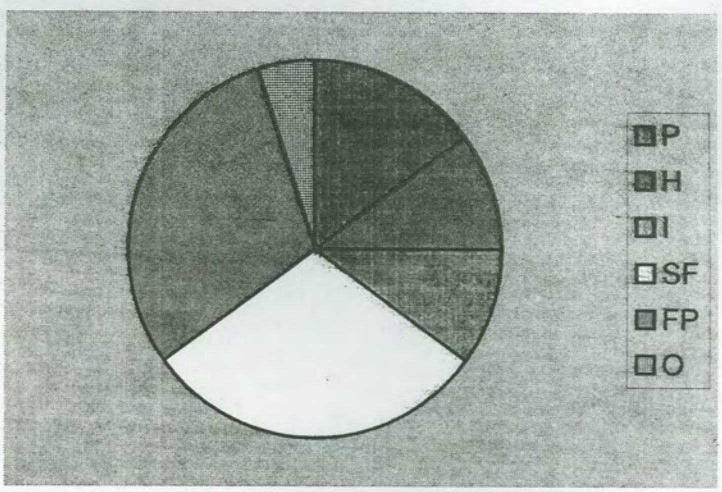
P = Plankton Feeder, H = Herbivore, I = Insect feeder



SF = Substrate feeder, FP = Fish feeder, O = Omnivore

Fig. 2. Fish fauna of partially managed reservoirs with Stocking

P = Plankton Feeder, H = Herbivore, I = Insect feeder
SF = Substrate feeder, FP = Fish feeder, O = Omnivore



TROPHIC CASCADE IN RESERVOIR ECOSYSTEM

Top-down control in the simplified trophic cascade of fish, large zooplankton like *Daphnia* and algae (phytoplankton) is no doubt highly significant in reservoirs. However, the patterns are not always straightforward. The difference between the effect of high fish densities and situation with no fish at all is usually clear-cut and supports the hypothesis that herbivores completely suppress the primary producers unless they are themselves suppressed by carnivores. It has been observed by many that algal biomass in an ecosystem, where fish remains as dominant biotic community, is regulated by the abundance and fluctuations of nutrients – bottom-up cascading effect on algae (Levitan *et al.,* 1984).

It has also been reported that with the increase in fish biomass due to individual growth, the zooplankton population first indicates discontinuity and ultimately reduces itself to a critical level and if the predation pressure continues further, it collapses (Mills *et al.*, 1987). A generalized food web in reservoir ecosystem is presented in Fig. 3.

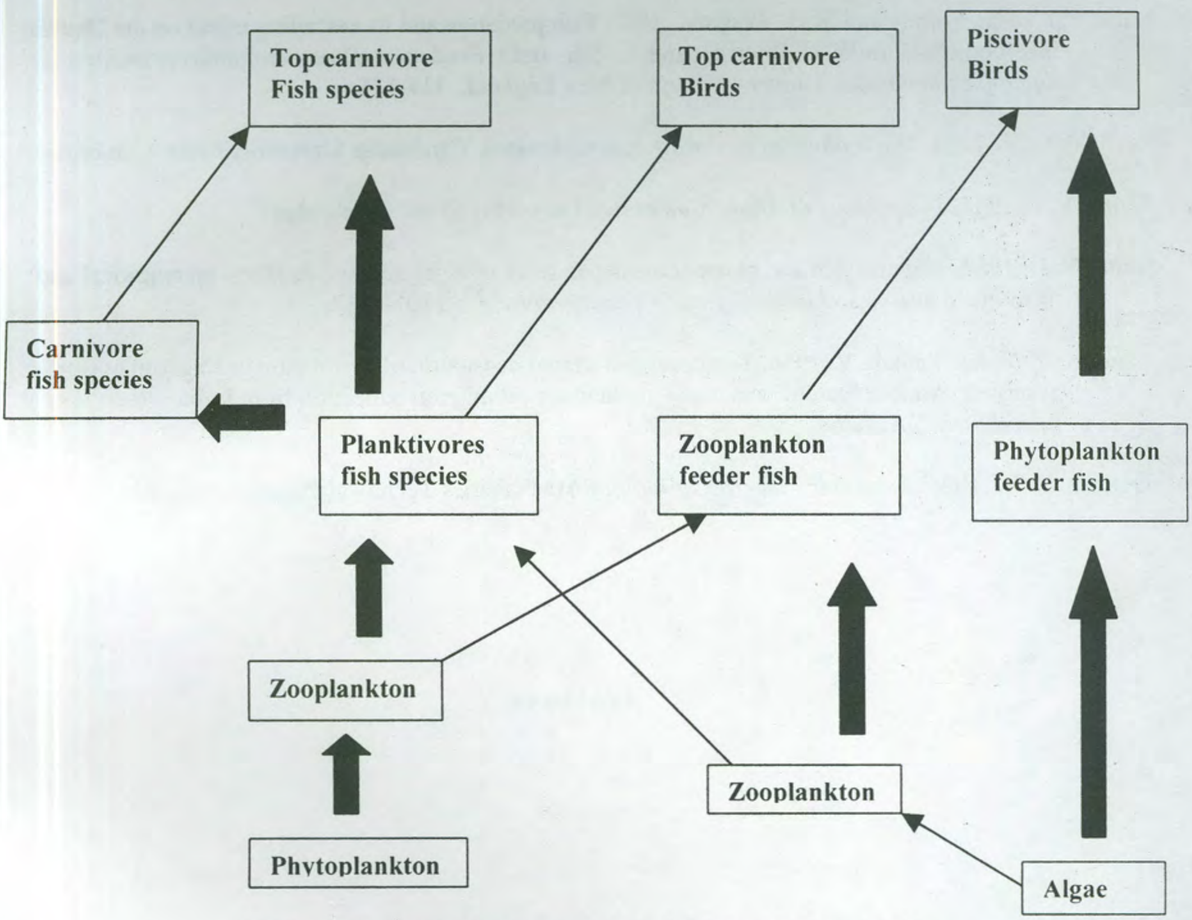


Fig. 3. A diagrammatic representation of food webs in reservoirs

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ROLE OF MACROPHYTES AND ASSOCIATED FAUNA OF FLOODPLAIN WETLANDS AND THEIR MANAGEMENT

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INTRODUCTION

Aquatic macrophytes comprise a diverse assemblage of macroscopic plants that spend whole or at least a part of their life cycle in aquatic environment. They include Spermatophytes (seed bearing plants), Pteriodophytes (ferns and fern allies), Bryophytes (mosses and liverworts) and algae (charophytes like *Chara, Nitella,* etc.).

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

Floodplain wetlands support in general the natural growth of a large number of minor economically important plants, molluscs, crabs and fishes which constitute some of the major elements of livelihood for the rural poor. But most of these wetlands in different river basins are now subjected to ecological stress. The fish yield of many of these water bodies are now as low as 10% of their actual potential. These highly potential water bodies along with their rich genetic wealth of plants and animals will get obliterated if left unmanaged.

MACROPHYTE DIVERSITY

Floodplain lakes receive water directly from precipitation and also flood water from rivers during monsoon. Along with water, they receive silt, organic and inorganic nutrients as well as seeds, propagules and many free floating aquatic weeds. Being shallow in nature with great euphotic zone they form one of the most favourable habitats for the growth of innumerable species of hydrophytes occupying different niches of the ecosystem. Depending upon the zonation pattern in the habitat, macrophytes are usually classified into the three major groups *viz*., emergent, floating and submerged.

Emergent macrophytes

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

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, Myriophylum tetrandrum, M. tuberculatum, Limnophila indica, Potamogeton nodosus, Aponogeton natans, etc.* These plants grow in continuous water zone having a depth ranging from 0.25 to 3 m.

The free floating ones are *Eichhornia crassipes, Pistia stratiotis, Spirodella polyrhiza, Lemna perpusilla, Azolla pinnata, Utricularia stelaris, U. aurea*, etc. They remain spread all over the water area or get drifted towards the bank by the wind action. In shallow waters some of them may anchor their extensive root system and develop into land forms.

Submerged macrophytes

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

MACROPHYTE ASSOCIATED FAUNA

Aquatic macrophytes support a dense growth of macro-invertebrate fauna by providing food, shelter, breeding ground and rearing area for their progenies. Bulk of this fauna is formed by the ubiquitous molluscs, followed by nymph, larvae and adults of insects, and 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 convexiculus, Gabia orcula, Bellamya bengalensis, V. doliaris, 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 waters mainly because of their partial adaptation to the aquatic life. There are seven to 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 (Tricop era, 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 beels of West Bengal thoroughout the year and occasionally met with in plenty as a constituent of the weed associated fauna.

Decapods

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

Annelids

The annelids are relatively fewer in number and are mostly represented by oligocheates (aquatic earthworms), polycheates and a few parasitic leeches belonging to the genera *Placobdella, Halobdella* and *Hirudo*. The common oligochaetes belong to the 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 the macrophytes.

Arachnids

Organisms like ticks, mites, water spiders are also found as constituents of the macrophyte associated fauna.

IMPACT OF MACROPHYTE AND ASSOCIATED FAUNA

1. A number of macrophytes, molluscs, crabs and fishes – the natural constituents of this wetland ecosystem - are regularly harvested by the rural poor as a means of their livelihood. For example, *Typha* and few species of *Cyperus* spp. are largely used as thatching material and weaving mats; pith of *Aeschynomene aspera* is used in 'shola' industry; *Ipomoea aquatica, Enhydra fluctuens* and species of *Alternanthera, Nymphaea* and *Nelumbo* as vegetables; *Euryale* and *Trapa* as cash crops, *and Bacopa monierri* (Brahmi), *Hygrophila auriculata* (Kulekhara) and *Marsilea quadrifolia* (Susni) as medicinal plants. In fact many of these minor animal food, vegetables and medicinal plants are commonly sold in suburban markets. Cultivation and processing of *Euryale* seed assumed great importance as a means of subsistance among the womenfolk of fisher community in parts of North Bihar.

2. The deposits of decaying macrophytes enrich the detritus pool of the bottom soil which in turn support a good bottom macro-invertebrate fauna mainly of molluscs – a favourite food for birds and some carnivorous fishes. Traditionally, duck farming in these water bodies is very popular in all peripheral villages. Further

being breeding ground of many rare and endangered species of migratory birds, of late conservation of many of these water bodies have attracted attention at national and international level.

3. Macrophytes is an important link in the food chain of this wetland ecosystem directly (microphytic food chain) and indirectly (macrophyte- associated fauna.

Besides, through photosynthesis, respiration and manner and rate of growth, aquatic macrophytes affect a number of environmental factors, such as concentration of dissolved oxygen, carbon dioxide, nutrient supply, pH value of both water and soil, light penetration and rate of silting. These, in effect, exert a direct or indirect influence on the lives of other aquatic organisms, notably the microflora and fauna for which macrophytes provide support, shelter and food.

AQUATIC MACROPHYTE MANAGEMENT

To maintain equillibrium in aquatic environment, growth of certain macrophytes in water is essential. But their excessive growth causes various problems adversely affecting proper utilization of these water bodies. By physically covering and choking the water body, they not only disrupt fish culture operation but also interfere with navigation, irrigation, drainage, *etc*. Besides, they also cause health problems by polluting water and harbouring vectors of many diseases. Their proper management therefore, assumes much importance in terms of economic, agricultural and conservation activities.

There are three well-established methods to check undesirable growth of macrophytes. These are (i) physical or mechanical method, (ii) chemical method and (iii) biological method.

(i) Physical or mechanical method

Physical removal of weeds using simple tools is an age-old method. The tools commonly used are scythes, dragnets for free floating weeds and drag chains for submerged weeds. To tackle the problems of greater magnitude manual or small power operated hand tools, and fully power operated weed cutting boats, harvestors, excavators, mowers, dredging machines, *etc*. have come into use. The harvested weed is usually sun dried and burnt unless some end use like fodder, manure, etc. can be found. This method is laborious requiring repeated operations and there is a risk of reinfestation by seeds, left over propagules, vegetative fragments, *etc*. Yet, there are some distinct advantages. This method does not pollute or degrade the water body and does not affect the non-target organisms inhabiting it.

(ii) Chemical method

Organic and inorganic herbicides have long been used with varying levels of success to control aquatic weeds in advanced countries. This method has been proved to be comparatively easier, faster and cheaper. But due to lack of infrastructural facilities it is still being used in very small scale in the developing countries in the tropics. When applying herbicides one must be cautious about the possible hazards to the users, the consumers of the water and the fishes. Some of the commonly used herbicides are :-

a) 2,4-D – Considered to be the best herbicide against *Eichhornia* and other broad leaved species. Fishes are tolerant to amine salt preparations but their flesh may impart temporary phenolic flavour. Trated water is also unfit for irrigation use.

b) Diquat and Paraquat – Both are effective against floating weeds like *Eichhornia, Pistia, Spirodela, Lemna, etc.* and submerged weeds like *Najas, Ceratophyllum, Myriophyllum, Potamogeton, etc.* These are non persistent and treated water is considered safe for all uses.

c) Dalapon or DCPA – A foilage active systemic herbicide, easily translocated to sub-terranean organs; effective against robust grasses and sedges. A mild skin irritant but considered not poisonous to man, livestock and probably to fishes.

(iii) Biological methods

Deployment of a suitable organism like fish, snail, insect and pathogen to check the growth and spread of weed to an acceptable limit is called biological control. Though this method of control is cheaper and has minimum detrimental side effects it has got its own limitations.

Fishes *like Ctenopharyngodon idella, Puntius javanicus, P. pulchellus, Osphronemus gourami* and *Cyprinus carpio* are known as good vegetation feeder. Among these, the Chinese grass carp – *C. idella* is considered to be the best which is reported to consume 40-70% of its body weight per day.

In Suraha tal (U.P.) and Loktak Lake (Manipur) weevils *Neochetina eichhorniae* and *N. bruchii* have shown encouraging results as biocontrolling agent against *Eichhornia crassipes*.

In Kerala, common tropical snail, *Pila globosa* has also proved to be a good biocontrolling agent against *Salvinia molesta*.

CONCLUSION

Floodplain lakes are important natural water bodies harbouring unique flora and fauna. In developing countries they support traditional subsistence activities of the rural poor, besides navigation, irrigation, drainage, and a host of other activities. Therefore, all management activities and conservation measures should be eco-friendly and compatible to the needs of the local communities whose lives are linked with these wetlands.

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Summer School on
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ENVIRONMENTAL CONSIDERATIONS IN MANAGEMENT OF FISHERIES IN SMALL WATER BODIES

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INTRODUCTION

The terms "small water bodies" and "wetlands" are used to describe such diverse habitats in different climatic zones of the earth that it is difficult to define them in simple terms. The definitions range from simple working types to highly technical ones. Wetlands are defined 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 meters. In India, there is no standard definition for small water bodies. They have to be identified and distinguished from other ecosystems by their ecological characteristics alone for their proper management. Small water bodies (SWBs) in India comprises mainly floodplain wetlands and small irrigation reservoirs.

It is also necessary to recognize a distinction between the natural and man made water bodies. In India, there are more man-made aquatic habitats than natural ones. Besides large areas of paddy fields, numerous fish ponds (often modified from the marshes) and shallow reservoirs. Most of these man-made SWBs are managed for specific economic activity whereas some are incidental to other forms of water resource utilization, such as irrigation. The management of man made SWBs has to take into account the fact that their hydrology is regulated by humans for various other reasons.

FUNCTIONS/VALUES

All small water bodies perform certain functions and hence, have some values. Sometimes, these functions and values are considered interchangeable. It must be stressed however that all form of SWBs do not perform all possible functions, and therefore do not have similar values. The functions depend upon the location, size, and various ecosystem characteristics, and also upon the nature and degree of human intervention. These functions can be broadly categorized as hydrological, biological and biochemical.

Hydrological function

This function bestows upon small water bodies their value for flood control (or flood mitigation) and aquifer recharge. The four main values are (a) flood water storage, (b) groundwater recharge, (c) source of water and (d) silt trapping.

Biological functions

High primary and secondary production by aquatic organisms and their role in nutrient dynamics confer upon wetlands many important values such as:

(a) habitat for wildlife; (b) sources of economically important biota; (c) storm abatement and
(d) control of soil/catchment erosion.

Biogeochemical functions

These functions and values are directly linked with following aspects in a wetland:

(a) regulation of water quality; (b) global cycles of gases; (c) socio-economic values; (d) socio-cultural aesthetic and recreational values and (e) health hazard.

FISHERIES AND SMALL WATER BODIES

Although fish production from the inland sector has increased significantly but major contribution has been from aquaculture. But to meet the targeted shortfall in fish production attempts have been made to develop technologies to enhance the fish yield of open-water resources especially from the small water bodies, which usually includes small reservoirs and floodplain lakes. Because of their resource base, productive potential and nutrient status they can be brought under different level of management to derive the benefits which the society or the littoral population along the wetland deem economically beneficial for them. In this context the ecological implication or the sustainability of the system is not taken into consideration.

Existing technology options to raise the fish production in small water bodies/reservoirs have not been adapted in a large scale so much so that significant quantum jump in production could not be achieved. However, through the sustained research efforts of scientists, it has been possible to demonstrate raise the fish production in small water bodies by application of scientific management. A few case studies of small water bodies in which scientific management has helped in increasing fish production are indicated in Table 1.

Table 1. Impact of Scientific management on fish yield

Name of water body	Fish Production (kg/ha/y)	
	Unscientific management	*Scientific management*
Aliyar (Tamil Nadu)	27	215
Bhavanisagar (Tamil Nadu)	30	94
Thirumoorthy (Tamil Nadu)	70	200
Gulariya (U. P.)	33	170
Bachhra (U. P.)	NA	110
Baghla (U. P.)	NA	150

MANAGEMENT OPTIONS

The common norms of fisheries enhancement, relevant to inland water bodies, are as under:

i) Stock enhancement
ii) Species enhancement
iii) habitat enhancement
iv) Management enhancement
v) Adoption of new culture systems

All the above options, designed to increase the fish yield from the systems, are bound to alter one or the other natural functions of the ecosystem, which may not be environmentally congenial for the systems as such or the biodiversity it holds.

ENVIRONMENTAL ISSUES

Best use concept

The small water bodies which are either natural or man-made serve in various ways to the society. It is necessary, therefore, that we should be extra careful in their management to increase fish yield, till the question of evaluation of their best use is addressed too.

Hydrological alterations

One of the basic strategies in making wetlands/small water bodies suitable for enhanced fish yield require alterations in its hydrological regime. In doing so many environmental changes are bound to affect the system and its functions as indicated as under:

i) Changes in the pattern of sedimentation, with consequences for silting and subsequent water movement.
ii) Loss of spawning areas for fish stocks or loss of nursery areas
iii) Possible barriers to the movement of fish stocks
iv) Alteration in biological communities, through loss of dilution capacity between inflow and outflow
v) Reduced turbulence and oxygenation due to low flow and possible loss of habitat due to stranding and desiccation above the waterline.

NUTRIENT ENRICHMENT

One of the main activities in fishery enhancement in a small water body involves improving its nutrient status to encourage higher productivity at all levels which enables to realise additional fish biomass. In majority of cases this nutrient up-scaling is not carried out on the basis of any nutrient balance/budgeting investigation. It results in nutrient imbalance in the system and is manifested in different degrees of eutrophication. The consequences of eutrophication are many and once the process sets in it becomes difficult to reverse this trend. It has a direct impact on water quality of the system which is reflected in higher loads of nitrogen and phosphorus. Unless the system has high water renewal factor these nutrients tend to get accumulated at various levels of food chain and set in motion host of changes in the system. The nitrogen levels tend to increase the levels of ammoniacal nitrogen. The total ammoniacal nitrogen is composed of ionized and unionized fractions and the unionized fraction is toxic to aquatic life. The increased levels of nitrogen and phosphorus have the potential to accelerate the productivity of macrophytes and algae resulting in macrophytes infestation or bloom formation. The process of eutrophication also alters the oxygen levels in the system affecting the oxygen requirements for fish species and other members of food-chain holding the production potential. This will consequently trigger changes in BOD levels thus affecting microbial communities in the system.

BIODIVERSITY CHANGES IN ECOSYSTEM

Darwin's theory of natural selection presumes that populations consist of individuals which have the properties of (I) high reproductive rate (ii) inheritance and (iii) variations. But the man-made changes in external factors *i.e.* anthropogenic changes, create new problems because new strains fitted to these changes do not develop overnight. Most natural changes have occurred many times previously and the genetic pool is, therefore, prepared to meet the majority of natural changes but not of the man-made changes. If an ecological parallel of Darwin's evolutionary chain is drawn on thermodynamic terms with energy as the basic concept, the prevailing conditions of an ecosystem are steadily changing and the system will continuously select the species that can contribute most to the maintenance of, or even growth of, the energy of the system.

IMPOSED SPECIES

The stock enhancement and species enhancements are two of the tools utilized for fish yield enhancement in a small water bodies. The stocks selected are primarily based on their availability of seed of that species in the market and the market demand of that fish or shell fish. These alterations in majority of cases have no consideration for the system sustainability and ecological demands. This stocking is like putting something in a black box which although may achieve the immediate objective of yield hike may result in ecosystem alteration. Ecological valuation of such changes may be difficult to make at that point of time. These implants in ecosystems may result in food-chain alterations down the level and set in motion the changes in species composition, self corrective capacity of the ecosystem for fighting various pathogens and diseases. In fact, unintentionally through this species enrichment we encourage monoculture of a specific species in a natural ecosystem which thus affect biodiversity and deflects the natural process of selection. The variations in species is one of the strong aspects of evolution.

CONCLUSION

All the environmental consequences of man-made modification on an ecosystem cannot be measured in tangible or quantitative terms, but there are some very clear impacts and some are hidden having long term implications. Therefore, while planning any kind of ecosystem intervention, whether for fisheries development or exploiting the system for any other benefit, the likely environmental impacts, both positive and negative, must be carefully evaluated for long-term sustainability of the ecosystem and biodiversity it contains.

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AQUATIC BIODIVERSITY IN INLAND FISHERIES MANAGEMENT

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INTRODUCTION

Biodiversity or biological diversity has assumed topical significance in recent times. This could be assessed from increasing usage of the word biodiversity in scientific literature, popular articles, Government reports, NGO bulletins and newspaper columns. Apart from the euphoria amongst the world community, a sense of uncertainty also prevails with regards to its maintenance at the safe level. The fact remains that the biodiversity assumed very high importance, especially after the 1992 Earth Summit in Rio de Janeiro. In the backdrop of such developments, it may be legitimate to ponder as to what does this word biodiversity actually mean and why so much of concern for its rational conservation.

Effective monitoring and proper measurement of biodiversity in a given place/ecosystem and in a given time become essential to understand the quantum and nature of available biological wealth. It is time to define our objectivity, in clear terms, related to biodiversity assessment, not only to satisfy the scientific quests, but also contributing to the issues of topical interest of concern at all level of the society.

DEFINITION AND A BRIEF HISTORY OF BIODIVERSITY STUDIES/CONSERVATION

The usage of biodiversity in a variety of contexts has a long history. However, its importance in current perspective started only recently, since 1980s, when three scientific articles published by Lovejoy (1980 a, b) and Norse & McManus (1980). The first two articles devoted more to describe number of species present, without giving any formal definition of biodiversity. The third article (Norse & McManus) employed two related concepts pertaining to biodiversity *viz. genetic diversity* and *ecological diversity*. Again in

1986 Norse *et al* expanded the usage of biodiversity, further, such as *genetic diversity* (within species), *species diversity* (species number) and *ecological (*Community*) diversity.*

The contracted form 'biodiversity', which is used commonly, has been coined by Rosen (1985) and used the same in National Forum on Biodiversity in the year 1986 in Washington DC. This is reinforced by the official definition in Article 2 of the 'Convention and Biological Diversity' signed by 156 nations including India at the UN Conference on Environment & Development, The Earth Summit, in 1992, which was incidentally, a replica of the concept put forward by Norse *et al.,* (1986). Accordingly, the biodiversity could be defined as:

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

It is necessary to follow the global norms for Biodiversity Assessment, wherein all three levels *viz. genetic, organismal/species* and *ecological* are being considered. Eldredge (1992) proposed *genealogical, phenotypic* and *ecological* in a parallel manner.

The first treaty on preservation of flora and fauna was formulated in 1993, but nothing tangible could be achieved till date owing to sectional nature of the efforts. In India the studies pertaining to biodiversity were sporadic till the setting up of a Department of Environment at the Central Government level in 1980, which was later converted into a full-fledged Ministry of Environment and Forest in 1985. After the creation of this Ministry, the activities under various agencies like Indian Council of Forestry Research and Education, Wild Life Institute of India, ZSI and BSI were mandated to formulate and execute conservation programmes. In addition to this 13 biosphere reserves, 63 National Parks, 358 Sanctuaries and 16 Wetlands have been identified for conservation of biodiversity by preserving their ecological integrity. Under the ICAR set-up, the work on biodiversity conservation, especially for domesticated species, has been entrusted to National Bureau of Plant Genetic Resources, National Bureau of Animal Genetic Resources and National Bureau of Fish Genetic resources. However, other Institutes like CIFRI and CMFRI are also working on certain aspects of aquatic biodiversity so as to create necessary database for future programming.

Attempts have also been made to give biodiversity conservation some kind of a legal status through *Wild Life Protection Act,* 1972 or many other acts. An estimated 20 Central Acts besides a large number of State Acts are in operation covering many aspects of biodiversity conservation such as wildlife conservation, *in situ* conservation *etc.* However, conservation of biodiversity of domesticated flora and fauna has not been covered adequately.

STATUS OF BIODIVERSITY ON EARTH

An estimated 30 million plant and animals exist on this planet. However, only 2 million plants and 1.5 million animals have so far been identified till date including the cultivated or domesticated species (Tewary, 1993). Evidently, the exact potential of genetic resources is yet to be evaluated fully. However, the rate of extinction amongst the existing biodiversity has assumed a serious dimension during the last 50 years owing to indiscriminate exploitation of biotic resources in the face of increased human pressure. The ongoing trend of biodiversity loss is a matter of serious concern, as it may lead to a catastrophic situation making the planet uninhabitable.

In India, 75,000 species of animals and 48,569 plants have been identified. The distribution under different groups is given in Table 1.

Table 1. Status of Biodiversity in India (Tewary, 1993)

ANIMALS		PLANTS	
Group	***Number***	***Group***	***Number***
Mammals	340	Flowering plants	15,000
Birds	1,200	Algae	4269
Reptiles	420	Lichens	1600
Amphibians	140	Fungi	20,000
Fishes	2,000 (960*)	Bryophytes	2,700
Molluscs	4,000	Pteridophytes	6,000
Insects	50,000		
Other invertebrates	16,900		

** Number of species in inland waters*

Status of aquatic biodiversity

According to the World Conservation and Monitoring Centre (1992, popularly known as WCMC, the inland ecosystems contain more than 1,000 species of vascular plants and approximately 40% of total fish fauna (8,400 species). It has been estimated that the mean number of species in freshwater is much higher than that of the species available in all other habitats. The inland waters of India harbour more than 150 species of aquatic plants and about 960 species of fish.

The aquatic ecosystems, including the seas, contain about 10,000 different species of phytoplankton, of which only 10% has been described till date (WCMC, 1992). In India nearly 4,269 species of algae comprising 890 species of phytoplankton of 653 genera, have been identified. A total of 3,023 species of algae have been recorded from freshwater, 1222 species from marine waters and 24 species common to both the environments. The freshwater ecosystems have wide variety of phytoplankton but there is paucity of information in this regard, barring some scattered studies. The pelagic stratum of lakes, for instance, is known to exhibit a complex biotope comprising huge varieties of microscopic organisms. Hutchinson (1961) has termed this complexity as *paradox of plankton,* which needs detailed probe, especially in Indian context.

It is believed that increase in species diversity is a function of maturation factor of an ecosystem (Odum, 1971). The evolution of new species, thus, is a function of time, as ancient ecosystems often exhibit high species richness and more endemism. However, the fast changing environmental variability in recent years, have been found responsible for producing new conditions and accordingly permitting new species to coexist (Sommer, 1985).

AQUATIC BIODIVERSITY – A FISHERIES PERSPECTIVE

Status and Trends of biodiversity in certain freshwater fisheries resources of India

Rivers

Studies conducted at CIFRI on various major river systems of the country such as Ganga, Brahamputra, Narmada, Mahanadi and Kaveri suggest a definite shift in fish catch structures (Sinha *et.al.,* 1998). The miscellaneous fishes of less economic value have over-taken all the other groups such as Indian major carps and large catfishes. In river Ganga, for instance, the fishery of Indian major carps (IMC) has declined to an alarming level (Fig. 1). Large-scale destruction of habitats in the face of irrational exploitation of biological resources could be identified as the main causative factor. The lucrative hilsa fishery of the past has completely collapsed in the river Ganga after construction of Farakka barrage. Contribution of hilsa to the total fish landing, above the Farakka barrage, has gone down to less than 1% in recent years as compared to 14% contribution during 1970s. This is a glaring example of man-induced impact like dams and barrages, which obstruct migration of fishes, from sea to freshwater and *vice versa.* Many other important fisheries of various river systems such as *mahseer* have reached a flash point and may collapse, if corrective measures are not initiated at the earliest. The fish spectrum of rivers alone may not be indicative of loss in fish biodiversity at the *organismal* level, but the prevailing poor growth of prized fish species like IMC or recruitment failure at times does suggest that the fish diversity has been affected at the genetic or physiological level, being exposed to various stress factors.

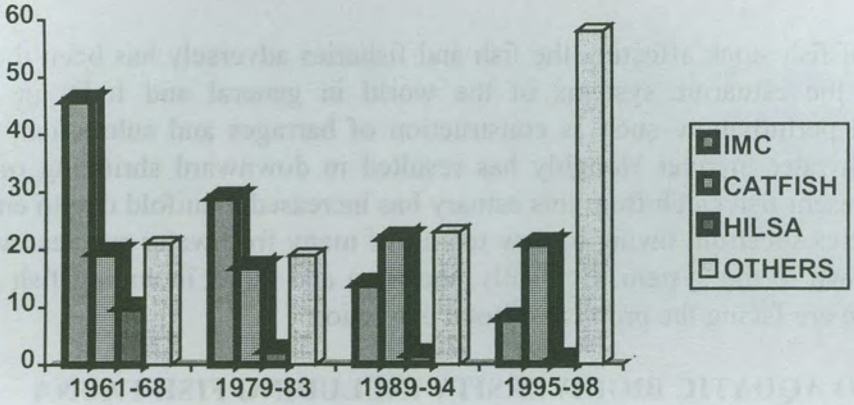

Fig. 1. A general trend of fishery in the river Ganga

Wetlands

The wetlands are highly threatened systems, most of them reeling under acute to very acute stages of eutrophication. Some are at the threshold of converting themselves into swamps. The rich biodiversity including fish fauna has been the characteristic of these water bodies, till recently. But of late, a definite shift in biodiversity, both at the levels of populations and organisms has taken place. Massive stands of macrophytes indicating a state of advanced eutrophication, have adversely affected the overall biodiversity of the lakes (Sinha & Jha, 1997, Jha & Chandra, 1997; Sugunan *et al.* 2000 a, b). In the face of increasing eutrophication, the general trend of biodiversity in wetlands can be characterized as:

- O Considerable shift in algal community from *diatom* to *green* and finally to *blue-green* dominance with persistent or intermittent blooms leading to erosion in effective grazing chain necessary for economically viable fishery.
- O Greater expansion of macrophytes, which leads to locking of nutrients and creating under water deserts by forming canopy at top.
- O Depletion of oxygen at benthic niche causing widespread elimination of benthic fauna and fish kills.

The wetlands no longer remain as the renewable source of fish and fishery in the backdrop of increasing aberrations owing to various man-induced modifications. The lakes have been subjected to stress of various dimensions and in the bargain the biodiversity is the worst casualty. Data available at CIFRI suggest that most of the floodplain lakes are losing their productivity, related to human welfare, at a faster pace. Presently, the lakes have greater dominance of forage and predators pushing the prized fish species to the rear.

Estuaries

Over-fishing of fish stock affecting the fish and fisheries adversely has been the hallmark in almost all the estuarine systems of the world in general and India in particular. Environmental perturbation, such as construction of barrages and subsequent release of excessive freshwater in river Hooghly has resulted in downward shrinking of estuarine stretch. The present fish catch from this estuary has increased manifold due to enlargement in its fish species spectrum owing to new recruit of many freshwater species, which were hitherto unknown to the system. Evidently, the flora and fauna including fish species of estuarine origin are facing the problem of total extinction.

THREATS TO AQUATIC BIODIVERSITY INCLUDING FISH FAUNA

The aquatic biodiversity is subjected to a number of threats, most of which have roots to man-induced modifications and irrational exploitation of aquatic resources. The natural resources in which fisheries waters are also a part are passing through a critical phase of ecological transition in recent times owing to increased population pressure. Anthropogenic interferences are known to have great bearing on water quality, which shape the abundance and texture of aquatic biodiversity. The following anthrocentric activities causing habitat destruction have been identified affecting natural biodiversity adversely:

- *Excessive & irrational abstraction of water*
- *Irrational disposal of domestic or industrial effluents*
- *More ingress of agricultural runoff containing hazardous chemicals and pesticides*
- *Large-scale river valley modifications*
- *Encroachment of water area, either drowned or drained for human settlement or arable land,*
- *Lopsided growth biota, unwanted in nature*

- *Over exploitation of biological resources for getting more biomass of food value, such as over fishing or destructive fishing, etc.*

- *Irrational introduction of exotic species*

Exclusively, for fish and fisheries, however, five major attributes have been identified *viz. Over-fishing* (12%), *Hybridization* (38%), *Pollution* (39%), *Introduction of Exotics* (66%) and *Change in Habitats* (74%) for the loss or extinction of fish fauna (Miller *et al.,* 1989).

It has been observed further, that the loss of and change to habitats have inflicted maximum harm to the fish fauna. The introduction of exotics can be treated as the second most dangerous proposition affecting the endemic population. In India Gobindsagar (Himachal Pradesh) is a glaring example of shift in fish biodiversity owing to introduction of exotics and following the *Gause's competitive principle*. It is an established fact that a niche cannot be occupied by two species. Introduction of new species is being done in anticipation of compensating the available vacant niche in a system, which boomerang at times, as happened in case of Gobindsagar where accidental release of *Hypopthalmihcthys moltric* resulted in a boom in the catch of exotic fish species leading to problems of marketing and disposal (Fig. 2 and 3).

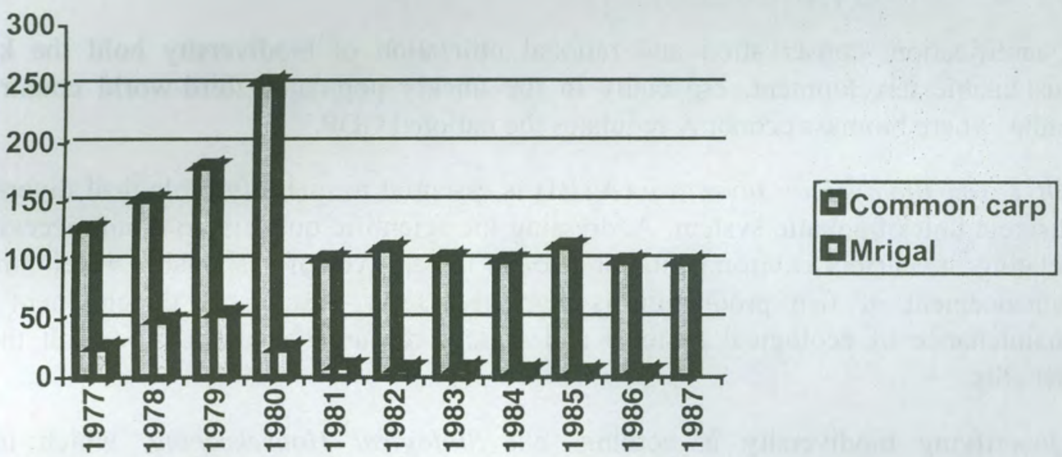

Fig. 2 a Impact of exotics on endemic fish in Gobindsagar

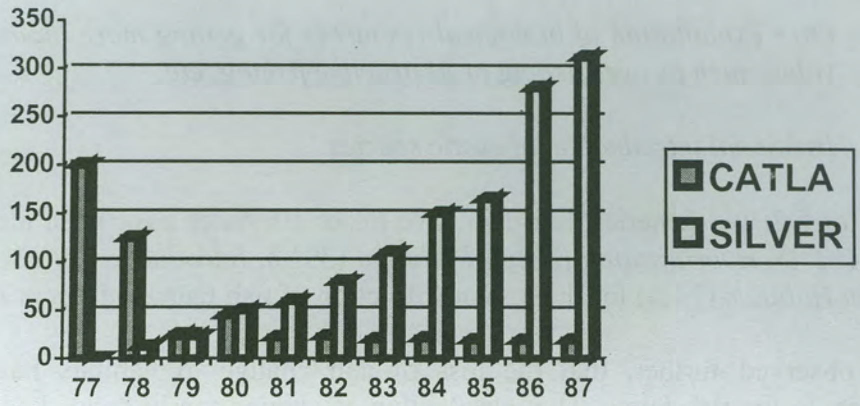

Fig. 3. Impact of exotics on endemic fish in Gobindsagar

Niche modification is another factor, which operates and affects aquatic biodiversity in the event of introduction of or invasion by new or exotic species. The wetland ecosystems in India for instance, are examples of this phenomenon, especially on account of the prolific growth of *Eichhornia crassipes.* It has resulted in modification of aquatic habitats converting these water bodies into swamps thereby affecting the endemic biodiversity and fisheries adversely.

CONCLUDING REMARKS

Quantification, conservation and rational utilization of biodiversity hold the keys for sustainable development, especially in the thickly populated third-world countries like India, where biomass economy regulates the national GDP.

All Taxon Biodiversity Inventory (ATBI) is essential to quantify biological diversity in a discrete unit of aquatic system. Addressing the scientific quest is no doubt necessary, but relating the current environmental and social imperatives of sustainable development like enhancement of fish production is also necessary. Sustainable development implies maintenance of ecological systems and natural resource bases in tune with the social benefits.

Quantifying biodiversity is nothing, but *Biological Housekeeping,* which involves-inventory, survey and monitoring of basic biological resources. This is necessary not only from precautionary point of view, but also to preserve the social, aesthetic, moral and economic importance associated with biodiversity. Conservation of biodiversity in its totality cannot be achieved without peoples' participation and high level of awareness among them. We cannot afford to lose our wild, domesticated or cultivated biodiversity beyond a point as it is directly linked with the growth and survival of mankind on this planet.

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YIELD OPTIMIZATION IN SMALL RESERVOIRS - A CASE STUDY IN TAMIL NADU

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INTRODUCTION

The state of Tamil Nadu has 58 small reservoirs and 8837 large irrigation tanks with an average area of 270 ha and 34 ha respectively (Sugunan, 1995). Further, the state possesses thousands of minor irrigation tanks with mean area of more than 10 ha each. The small reservoirs including irrigation tanks attract special importance, as they are easily manageable with comparatively less inputs. However, a majority of these productive water bodies remains fallow or underutilized due to various reasons such as less priority given to fishery development, meagre budget provision to the sector, lack of understanding of the environmental conditions and shortage of appropriate culture techniques. Hence, the fish yield from small reservoirs works out at less than 50 kg /ha/year (Sugunan,1995). Central Inland Capture Fisheries Research Institute carried out research work with an aim to evolve appropriate management techniques for enhancement of fish production from small reservoirs. The management norms followed in Aliyar and Thirumoorthy reservoirs in Tamil Nadu for achieving fish yield optimization are dealt in this communication.

ALIYAR AND THIRUMOORTHY RESERVOIRS

Aliyar and Thirumoorthy are small reservoirs under Parambikulam-Aliyar Project (P.A.P.), located in Bharathapuzha basin in the Western Ghat region of Tamil Nadu. In addition to the surface run-off from catchment area, they receive the main supply of water from Parambikulam reservoir through a contour canal. The higher catchment area and C/A ratio at Aliyar indicate the possibilities for higher allochthonus inputs into the reservoir. Located in the rain-shadow region of the Western Ghats, these reservoirs receive an average annual rainfall of around 700 mm as against the national average of 1050 mm. The location, morphometric features, hydrological and biological characteristics of Aliyar and

Thirumoorthy reservoirs are shown in Tables 1 and 2. Based on the prevailing ecological conditions in these two reservoirs they can be considered mesotrophic status on trophic scale. The fish production potential assessed through primary production is 412 kg/ha in Aliyar and 267 kg/ha in Thirumoorthy. The studies on the food and feeding habits of commercial fishes suggested that they relied more on detritus for their nourishment. Maturation studies reveal that the gonads in major carps develop only up to IV stage of maturity, beyond which resorption starts, leading to breeding failure in the reservoir. Studies on the gonado-somatic index (GSI) of major carps give low values (6.2 to 10.5) indicating non attainment of full maturation or spawning activities. In the absence of natural recruitment of major carps, stocking of quality fish seed becomes the most important management tool to optimize the yield from these reservoirs.

FISHERY MANAGEMENT IN ALIYAR AND THIRUMOORTHY RESERVOIRS BY THE DEPARTMENT OF FISHERIES AND THE TAMIL NADU FISHERIES DEVELOPMENT CORPORATION

In the initial years, the reservoirs were stocked heavily (303 - 2452 Nos./ha) with fish seeds of all available varieties belonging to medium carps, minor carps, major carps, predatory fishes, exotic fishes and even euryhaline fishes by state department of fisheries. The stocking was normally done within a short period from August to October, leading to a heavy competition among them for food and shelter. The fish seed used for stocking were small in size (20 - 40 mm) falling easy prey to the carnivores. The stocking density and species composition were also arbitory and lacked rationality in terms of available natural food at ecosystem level. The net result was poor growth performance of stocked species. In the absence of regulation in fishing, gill nets of very small mesh size were also operated by the fishermen for catching all size groups of fish. Hence, stocked fish did not get sufficient period for attaining marketable size fetching low market price. The recovery of stocked fish was very poor leading to low yield from the reservoirs (26.2 kg/ha in Aliyar and 63.6 kg/ha in Thirumoorthy) during the state management.

CHANGES MADE BY CIFRI IN THE FISHERY MANAGEMENT OF THE RESERVOIRS

Under CIFRI's management, earlier practice of stocking the reservoir with smaller seeds of medium and minor carps, predatory fishes and estuarine fishes was dispensed with. Fingerlings of Indian and exotic major carps of more than 100 mm in length were stocked. Fry and early fingerlings (20 - 40 mm long) of Indian and exotic carps were reared in fish farms available in the vicinity of the reservoirs to raise stocking material (> 100 mm). Stocking was done in small instalments at an interval of 7 to 10 days covering all the months of the year, instead of releasing the entire quantity of seed during a short period. As the size of the seed at stocking was increased, the density (nos./ha) was drastically reduced. The rate of growth of stocked species of fish was monitored through marking techniques. Fin-clipping and tagging experiments were conducted for this purpose (Murugesan and Selvaraj, 1990 a, Murugesan *et al.,* 1990 b and Murugesan *et al.,*1997). The rate of stocking and species ratio were adjusted according to the ecological conditions of the reservoir, growth potential of the stocked species and the overall biogenic capacity of the reservoir. Harvesting of fishes weighing more than 1 kg by employing gill nets with mesh exceeding 100 mm. The stocking and harvesting were spread throughout the year.

IMPACT OF STOCKING OF FINGERLINGS ON THE YIELD OF ALIYAR RESERVOIR

The species-wise stocking of fish seed in Aliyar reservoir during different years are shown in Fig-1. The the fish yield reached an optimum level within five years of scientific management (Fig-2). The contribution by stocked varieties of fish also increased substantially (85 - 99 %) in the total fish catch during this period. Among the different species, the contribution in case of *C. catla* was the highest followed by *C. mrigala, L. rohita* and *C. carpio.* The average catch per unit of effort (CPUE) was low (4.95 kg) during 1984-85, but the value gradually increased to a maximum of 16.91 kg during 1988-89. Since major carps of > 1 kg size were harvested, they fetched higher market price, the revenue to the state increased by 669%, while the income of the fishermen improved by 300%.

THE FISHERIES OF THIRUMOORTHY RESERVOIR UNDER SCIENTIFIC MANAGEMENT

The stocking rate was reduced to 215 fingerlings/ha during 1991-92. It was gradually increased in the subsequent years (Fig-3) ranging from 215 to 606 fingerlings/ha with an average of 387 nos/ha during the period 1991 to 97. In species compositon, *C. catla* was dominant (29.5%), followed by *C. carpio* (28.2%), *L. rohita* (24.1%), *C. mrigala* (16.9%) and *H. molitrix* (1.2%). The fish yield of Thirumoorthy reservoir started increasing from the first year (1991 - 92) of scientific management and reached an all time record of 213.4 kg/ha during 1996-97 (Fig-4). The stocked fish formed the major fishery (88.5 to 96.4 %) of the reservoir. The stocking of advanced fingerlings in healthy condition indicated positive impact on fish yield. The catch per unit of effort increased from a low value of 5.65 kg in 1991-92 to a maximum of 12.5 kg in 1994-95, improving the earnings fishermen community.

CONCLUSION

The case studies made in Aliyar and Thirumoorthy reservoirs of Tamil Nadu have clearly established that increase in fish yield is not only the function of higher stocking rate, but also depends on the size of the seed, health condition, species composition and the stocking density. A strict regulation in the mesh size of fishing gears restricting to capture fish weighing more than one kilogram only also paid divident. The stocking of fish in a phased manner covering all the months of the year compensated the reduction in the stock of cultivated carps due to harvesting, escapement, natural mortality, *etc.* Maintenance of optimum population of fast growing fishes which have better compatibility and conversion efficiency of ingested food into flesh is an important management measure to channelize the natural production potential into fish production. The management techniques evolved and applied at Aliyar and Thirumoorthy facilitated the optimization of fish yield from these small reservoirs. Adoption of these management techniques in other small reservoirs would certainly enhance the inland fish production of the country many fold.

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Table 1. Salient features of Aliyar and Thirumoorthy reservoirs

Parameters	Aliyar	Thirumoorthy
Location and morphometry		
River	Aliyar,Chinnar &Chittar	Palar & Nagappa naicker Odai
Basin	Bharathapuzha	Bharathapuzha
Year of impoundment	1962	1967
Catchment area-C (ha)	46880	8029
Reservoir area at FRL-A (ha)	646	388
C/A ratio	72.6	20.7
Gross capacity at FRL (M.cu.m)	109.4	54.8
Mean depth (m)	16.9	14.1
Mean area (DSL+FRL/2) (ha)	324	234
Average annual rainfall (mm)	706.9	723.4
Soil Quality		
pH (units)	6.0 - 6.9	6.4 - 7.9
E.C. (mmhos/cm)	-	0.1 - 4.2
Organic carbon (%)	0.7 - 1.0	0.26 - 4.1
Available Nitrogen (mg/100 g)	25.5 - 32.5	30.9 - 54.0
Available Phosphorus (mg/100 g)	2.5 - 4.0	0.2 - 0.8
Water Quality		
Temperature (°C)	21.2 - 32.5	22.0 - 34.0
Transparency (cm)	108 - 182	45 - 238
pH (units)	6.6 - 8.8	6.1 - 8.2
D.O. (ppm)	4.2 - 11.6	4.4 - 9.0
Free CO_2 (ppm)	0 - 10.0	0 - 5.0
Total alkalinity (mg/l)	16 - 58	12 - 33
Sp. conductivity (µmhos/cm)	38.7 - 109.6	21.7 - 59.1
Nitrates (mg/l)	Tr. - 0.02	-
Phosphates (mg/l)	Tr. - 0.04	0 - 2.0
Silicates (mg/l)	2.8 - 24.0	5 - 16
Organic matter (mg/l)	0.9 - 3.6	4 - 14.5

Table 2. Biotic communities and primary production

Communities	Aliyar	Thirumoorthy
Plankton (u/l)	924 - 16145	4072 - 20149
Plankton (ml/m^3)	6.4 - 19.9	2 - 6
Phytoplankton (%)	89.6	95.4
Zooplankton (%)	10.4	4.6
Periphyton (u/mm^2)	5 - 65	67 - 101
Macrobenthos (Nos/m^2)	56 - 2331	1175 - 1562
Primary production		
Gross (gC/m^2/day)	0.278 - 0.699	0.255 - 0.334
Net (gC/m^2/day)	0 - 0.385	0.203 - 0.238

Fig.1. Fish seed stocked in Aliyar reservoir

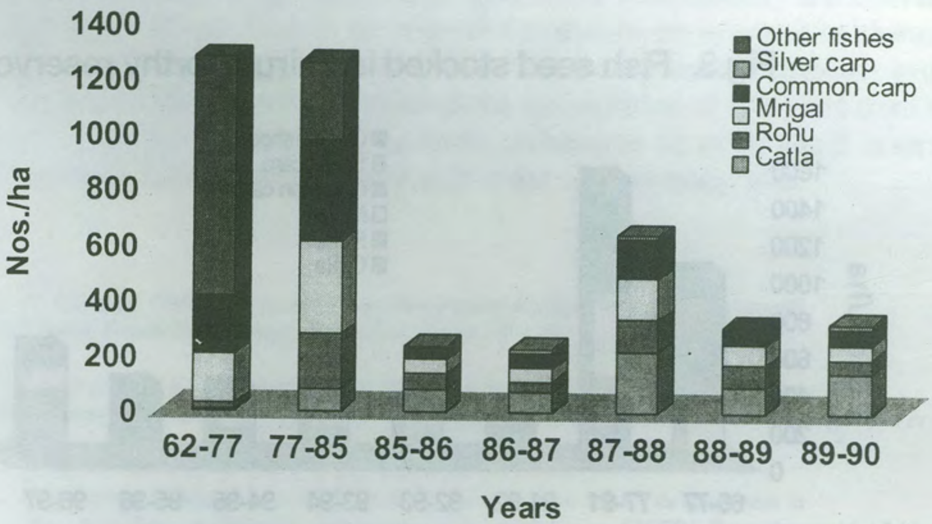


Fig. 2. Fish yield from Aliyar reservoir

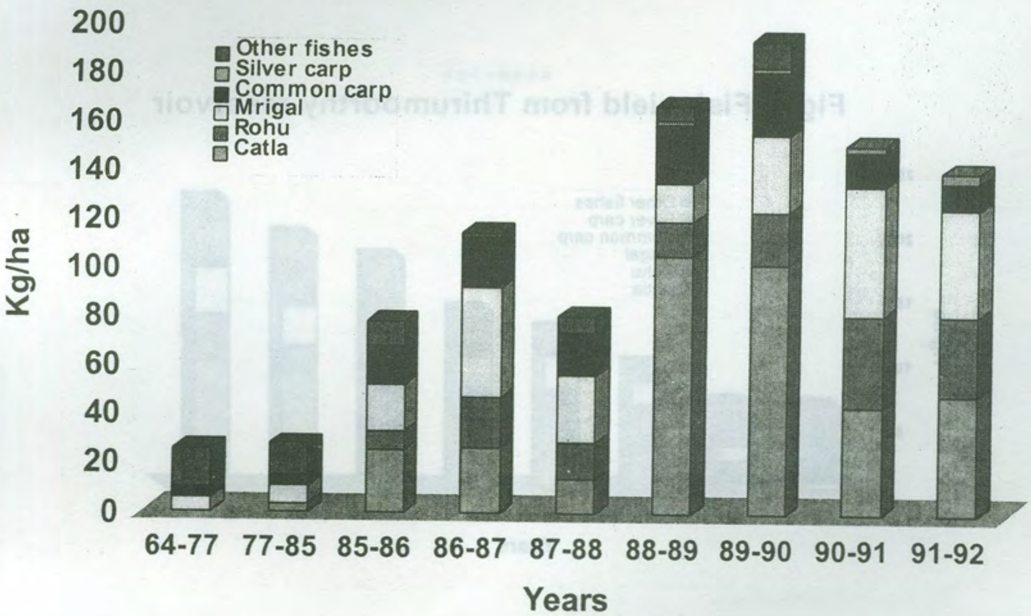


Fig.3. Fish seed stocked in Thirumoorthy reservoir

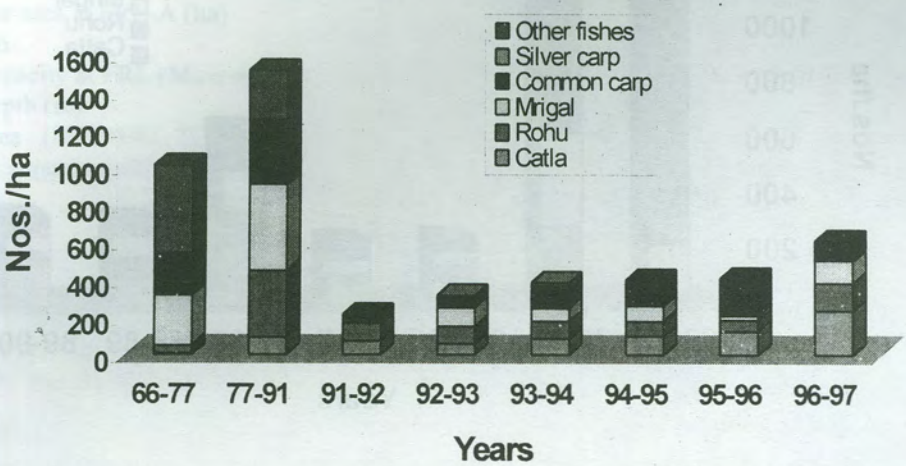
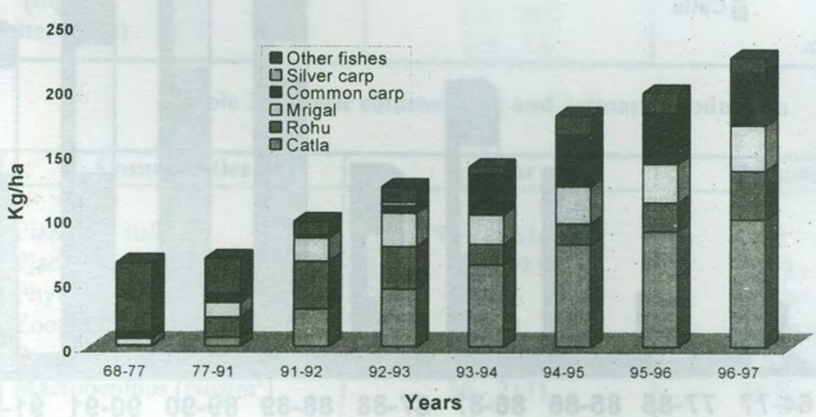


Fig.4. Fish yield from Thirumoorthy reservoir



Summer School on
Culture-based Fisheries for Inland Fisheries Development
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SMALL RESERVOIRS OF INDIA AND THEIR SUITABILITY FOR DEVELOPMENT OF CULTURE BASED FISHERY

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INTRODUCTION

At present, very little contribution in terms of fish production comes from reservoirs, though there exists tremendous potential of fish production to the tune of 200 kg/ha/annum. The present annual fish production from small reservoirs in India fluctuates from 3.9 kg/ha in Bihar to 188 kg/ha in Andhra Pradesh (Sugunan, 1995). The reason for this dismal low production is lukewarm attitude of the authorities towards their development besides unscientific management of this valuable resource. Reservoirs not only offer immense production potential, but also ensure employment to large number of fishers. According to an estimate (Sinha, 2000) small reservoirs, if, managed on scientific lines, can give employment to about 0.891 million fishers.

THE RESERVOIR RESOURCE

Total water spread under reservoirs in India is 3,157,366 ha (Sugunan, 1995). It consists of 1,485,577 ha of small reservoirs, 507,298 ha of medium reservoirs and 160,511 ha of large reservoirs. The reservoirs which are having an area < 1000 ha, between 1000 to 5000 ha and > than 5000 ha have been designated as small, medium and large reservoirs respectively (Table 1). At present, small reservoirs, on an average, give a fish production of 49.9 kg/ha/annum (Sugunan & Sinha, 2000). Out of large numbers of small reservoirs (>19,000), the fish production trend is available for 291 reservoirs only. This is again a case of low priority given to the development of this resource.

STATUS OF RESERVOIR FISHERIES IN INDIA

The biological evaluation of reservoirs and their fish production potential was not done on scientific lines till 1970s, when the yield from them stood at low level of 5 to 8 kg/ha/annum. The investigations conducted till then were limited to a few reservoirs spread over different states. Organized large-scale research on reservoir fisheries was initiated in the country only in the year 1971 with the launching of an *All India Coordinated Research Project on Ecology and Fisheries of Reservoirs* under the aegis of CIFRI. The studies continued up to 1981. Under this project, emphasis was laid towards ecological management for harvesting maximum sustainable fish yield. Consequent to these studies, significant increase in fish production was achieved from the reservoirs like Rihand, Govindsagar, Nagarjunasagar and Bhavanisagar.

During the same period, the Riverine and Lacustrine Division of the CIFRI initiated research projects on the development of small reservoirs to establish a database. These research efforts have culminated in formulation of management measures for fishery developments in many small reservoirs including Loni, Kulgarhi, Govindgarh, Naktara (Madhya Pradesh), Gulariya, Bachhra, Baghla (Uttar Pradesh), Aliyar, Thirumoorthy (Tamil Nadu), Kyrdemkulai, and Nongmahir (Meghalaya). In these reservoirs, investigations on water and soil characteristics, primary productivity, plankton, macrobenthos and macrovegetation have been conducted. The results emanated from the studies conducted in these reservoirs are very remarkable, as the fish yield increased several times (200 kg/ha/yr) from the existing level on account of use of management practices based on ecological parameters. The guidelines for management developed through these studies set the direction for enhancing fish yield from small reservoirs in the country.

CHARACTERISTICS OF RESERVOIR ECOSYSTEM

The quality of impounded water varies from watershed to watershed depending on soil, climatic conditions and anthropogenic activities. Owing to these variables evaluation of specifics of water quality has to be made separately for different sets of ecological families of reservoirs sharing the similar geo-climatic conditions although some generalization about their productivity can be made.

For successful fish culture in reservoirs, it is imperative to have a thorough understanding of the alterations the impoundment has caused in the environment and biotope. Impoundment immediately changes a lotic environment into a lentic one with the lotic condition retained during at least a part of the year. The rheophilic fauna and flora are replaced by lacustrine ones. Immediately after impoundment, there occurs a phase of trophic burst caused by nutrients leaching from the submerged vegetation and other organic matter, accelerating the growth of bacteria, plankton and benthos. The initial fertility peak in the reservoir lasts for a few years depending on climatic conditions mainly governed by temperature. The fertility declines after a few years and settle approximately to half of the initial level after a few years, partly due to diminution of bottom leaching and partly as the nutrients are used by aquatic vegetation.

DETERMINANTS OF BIOLOGICAL PRODUCTIVITY

Biological productivity of an impoundment is influenced by a host of factors, *viz.*, climatic, edaphic and morphometric. The geographic location affects the metabolism of the reservoir through nutrient supply, shape of the basin and the efficiency with which the climatic factors are able to act in the dynamic exchange. They will have varying effects on final productivity. The climatic factor has a profound effect on the utilization of the nutrients in a particular water basin. The low water temperature retards the fish growth while the higher accelerates. The edaphic factors affect the supply of the dissolved nutrients in the reservoir water. Soil basin quality influences the reservoir productivity to a great extent. Area, mean depth and regularity of the shoreline are the most important morphometric measurements having a significant bearing on the productivity at various trophic levels. The important chemical parameters and their range that may count for the productivity are listed in Table 2.

MANAGEMENT STRATEGIES FOR SMALL RESERVOIRS

Small reservoirs offer immense potential for pisciculture through extensive aquaculture techniques based on the principle of culture-based fisheries. They can contribute significantly to the country's inland fish production, if managed scientifically. Proper stocking and harvesting schedule, selection of right species for stocking and employing appropriate gear are the keys to successful management of these water bodies.

Past and present status of small reservoir fisheries

Fish culture in the small reservoirs, hitherto being practiced 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 latter years due to inadequate follow-up in management. This emphasizes 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. Range of key limno-biological parameters of certain small reservoir which CIFRI has conducted studies are portrayed in Table 3.

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 practice 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 4). 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 biotope, 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 get so drastically reduced that over-fishing takes place leaving no brood stock to contribute to the succeeding year's fishery through natural recruitment. Consequently, the entire catch from these water bodies depends on the fishes stocked from outside to offset this loss. Thus, there establishes 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 *a,* Selvaraj *et al*., 1990 and Dwivedi *et al*., 2000). Stocking is, therefore, a useful tool for the management of small reservoirs. The number of fish to be stocked per unit area is 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.

A number of methods are in vogue for assessing the potential fish yield from lakes and reservoirs (Jhingran, 1986, Khan *et al*., 1990 b). 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 b).

CASE STUDY OF BACHHRA RESERVOIR

Description of the reservoir

The reservoir came into being as a result of damming of the Bachhra rivulet in 1981. The reservoir is situated in Meja-Tehsil of district Allahabad approximately 55 km from Allahabad. The water-spread area at FSL (111 m above MSL) is 140 ha. The gross storage capacity is 7.42 million m^3 and 0.03 million m^3 at FSL and DSL respectively. The average depth of the reservoir is 5.22 m. An irrigation canal also originates from the bed level of the reservoir. Reservoir does not completely dry up in the summer and maintains a minimum widespread area of about 2 to 3 ha. The catchment area consists of rocky terrain covered with sparse forest and receiving an average rainfall of 900 mm/annum.

Fish and fisheries

Fish fauna comprises 51 species mainly belonging to carps and catfishes. Weed fishes dominated the reservoir at the initial filling (1980), though their population was very sparse. The reservoir was auctioned by the Irrigation Department in 1981 and all the fishes were caught through various types of gear and also by poisoning. When the reservoir was taken on lease from the irrigation department by CIFRI in 1985, the entire stock had to be rebuilt through stocking of major carps fingerlings. The reservoir was auctioned for a sum of Rs.63,000/- in 1986. The total catch was 4.85 t and the fish yield was calculated at 67.6 kg/ha. The low yield was due to incomplete harvesting as the right of the contractor was terminated in the middle of the season. The reservoir could not be auctioned in 1987 due to low bidding. However, it was again auctioned in 1988 for an amount of Rs. 32,300.00 and a production of 10.0 t (139 kg/ha) was obtained.

Estimation of potential fish yield and the stocking rate

The potential fish yield of the reservoir was estimated by using trophodynamic model based on energy flow through different trophic levels and standing crop of fish .The annual carbon production for Bachhra Reservoir fluctuated between 1,250 t and 1,402 t during 1985 to 1987. Based on the concept of Odum (1960), 1.2% of primary production is considered as a good conversion to fish flesh. This way, the reservoir should give a fish yield of 212 to 240 kg/ha. Against this, an actual fish yield of 67.40 and 139 kg/ha was obtained, the conversion efficiency being 0.314% to 0.58 % during 1986 and 1988 respectively.

The stocking rate for the reservoir was estimated on the basis of its potential fish yield of 212 to 240 kg/ha (1985-1987). Further, assuming that about 80% of the potential fish yield

(173 kg/ha) would be harvestable in view of the drastic diminishing water level, the stocking rate was computed by using the following formula:

$$\text{Stocking rate} = \frac{\text{Total production in kg}}{\text{Individual growth in kg}} + \text{loss due to mortality and escapement}$$

Growth rate was estimated based on recovery of tagged fishes. Assuming an average growth rate of 400 g per annum for major carps and a loss allowance of 75% (in view of escapement of fingerlings through irrigation canal, natural mortality and predation loss). Stocking rate was calculated as :

$$\text{Stocking rate} = \frac{173}{0.4} + \text{loss } (75\%) = 432 + 324 = 756 \text{ fingerlings/ha}$$

The total fingerlings required for an area of 72 ha (half of the FSL) was 54,432, say 55,000. Therefore, 55,000 fingerlings of major carps (average size 55 mm) comprising mrigal (45%), rohu (40%) and catla (15%) were stocked in 1985. Total stocking figures for 1986 and 1987 were 37,000 and 63,000 respectively. The stocking rate was reduced in 1986 in view of the profuse breeding of carps.

Finally, it may be concluded that fish production from small reservoirs can enhanced from 2 to 3 times from existing fish yield if managed on scientific line as explained in this communication.

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Table 1. Distribution of small, medium and large reservoirs in India- by State

(After Sugunan, 1995)

States	Small	Medium	Large	Total
Tamil Nadu	315,941	19,577	23,222	358,740
Karnataka	228,657	29,078	179,556	437,291
Madhya Pradesh	172,575	149,259	138,550	460,384
Andhra Pradesh	201,927	66,429	190,151	458,507
Maharashtra	119,515	39,181	115,054	273,750
Gujarat	84,124	57,748	144,358	286,230
Bihar	12,461	12,523	71,711	96,695
Orissa	66,047	12,748	119,403	198,198
Kerala	7,975	15,500	6,160	29,635
Uttar Pradesh	218,651	44,993	71,196	334,840
Rajasthan	54,231	49,827	49,386	153,444
Himachal Pradesh	200	-	41,364	41,564
Haryana	282	-	-	282
West Bengal	732	4,600	10,400	15,732
Northeast	2,239	5,835	-	8,074
Total	1,485,557	507,298	1,160,511	3,153,366

Table 2. Physico-chemical features of Indian reservoirs (range of values)

(After Jhingran, 1990)

Parameters	Range of values		
	Low	*Medium*	*High*
A. Water			
pH value	<6.0	6.0-8.5	>8.5
Carbonates (mg l^{-1})	<35.0	35-80	>80.0
Alkalinity (mg l^{-1})	<40.0	40-90	>90.0
Nitrates (mg l^{-1})	negligible	up to 0.2	0.2 –0.5
Phosphates (mg l^{-1})	negligible	up to 0.1	0.1 – 0.2
Specific conductivity (µS)		up to 200	>200
Temperature (^{0}C) (with minimal stratification)	18	18 –22	>22
B. Soil			
pH	<6.5	6.5 – 7.5	>7.5
Available P (mg/100g)	<3.0	3.0 –6.0	>6.0
Available N (mg/100g)	<25.0	25 –60	>6
Organic carbon (%)	<0.5	0.5 – 1.5	1.5 – 2.5

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

Parameters	Reservoirs					
	Gulariya	Bachhra	Baghla	Aliyar	Chappar-wara	Kyrdem-kulai
Transparency (cm)	11.0-80.0	17-145	9-204	108-182	-	2.2-2.84
Dissolved Oxygen (mg l^{-1})	4.9-9.0	2.5-8.6	2.4-12.8	4.2-11.6	6.1-10.0	6.7-7.1
pH	7.2-8.4.	6.9-8.3	7.3-8.8	6.6-6.8	8-8.40	6.8-7.0
Free CO_2 (mg l^{-1})	0-4.0	0-7.20	0-3.0	0-10.0	0	2-2.6
Alkalinity (mg l^{-1})	38-80	95-190	42-106	16-72	76-100	22-32
Hardness (mg l^{-1})	13-34	21-80			-	18.6-27.8
Nitrate (mg l^{-1})	0.08-0.20	0.08-.18	0.28-0.3	-	0.4-1.1	0.02-3.6
Phosphate (mg l^{-1})	0.05-0.13	0.06-0.25	0.28-03	Tr-0.4	0.11-0.16	Tr-0.02
Silicate (mg l^{-1})	5-14	6.8-14	2.4-4.9	Tr-0.2	1.9-8.0	1-10
Plankton (u l^{-1})	245-1060	70-8432	58-10000	-	3100-20100	8420*
Macrobenthos (u m^{-2})	95-1169	342-4620	976-2132	-	110-947	134*
Macrovegetation (u m^{-2})	absent	absent	250-2200	absent	470-1350	absent

(* indicates average values)

Table 4. High fish yields obtained in small reservoirs due to management based on stocking

(After Sugunan, 1995)

Reservoirs	State	Area (ha)	Stocking rate (no/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	-	102
Bundh Beratha	Rajasthan	-	164	94
Chapparwara	Rajasthan	200	300	79

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DEVELOPMENT OF MANAGEMENT GUIDELINES FOR CULTURE-BASED FISHERIES IN *BEELS*

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INTRODUCTION

*Beel*s are the natural lakes associated with the lower stretches and coastal plains of the rivers 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 their origin, water renewal pattern, water and soil quality and fauna and flora. They 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 *beels*.

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. 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 in selecting management option are those:

i) abetting primary productivity (soil and water quality),
ii) affecting composition of community, and

iii) determining their efficiency to transfer energy from one trophic level to the other

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, apart from being more cost-effective, will do minimum damage to ecosystem and biodiversity. There is a growing dichotomy between intensive aquaculture and the more eco-friendly option 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 point of view 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.

COMMUNITY METABOLISM IN *BEELS*

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 the 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 channeled 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 Figures 1 & 2. In both the cases, the birds are at the apex of the food chain. In the open system, 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, the closed 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.

MANAGEMENT OPTIONS

The management systems to be followed in the *beel*s should aim at taking maximum advantage of the existing food chains. In broad terms, it can be stated that the closed beels should be managed on lines of culture-based fisheries and the open ones should follow the capture fishery norms. But it is not easy to set thumb rules on the basis of this classification due to the presence of many intermediate situations. 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

*Beel*s retaining their riverine connection for a reasonably long time are relatively free from weed infestations. They 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 *beels* 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 into 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) Allowing free migration of brooders and juveniles from *beels* to river and *vice versa*
iii) Protection of brood stock and juveniles by conservation measures.

The growth over-fishing 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 summarized as:

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. *Beel*s are the ideal water bodies for practicing 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 *beel*s 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 summarized 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

Capture and culture-based fisheries

There are systems which combine the norms of capture and culture-based fisheries. The marginal areas of *beel*s are cordoned off for culture systems either as ponds or as pens and the central portion is left for capture fisheries (Fig 3). This has been tried in some *beels* of Manipur with certain degree of success.

SPECIES ENHANCEMENT

Species enhancement is a very important tool in the *beel* fishery management. There are various species options. It is customary to stock these water bodies with the Indian major carps viz., catla, rohu and mrigal along with grass carp for keeping weeds under check. But the indigenous species are equally important.

Indian major carps

The *beels*, especially the closed ones can be developed as culture-based fisheries as their fishery solely depends on stocking with Indian major carps (IMC). Although not done in a scientific way the *beels* are generally being stocked regularly with IMC. In the absence of natural recruitment, stocking with IMC species form the best management option. They are known for fast growth and effective utilization of available food niches. Species ratio should be determined depending on the relative strengths of fish food biotic communities such as plankton, benthos, detritus, *etc*. While stock enhancement through inducting IMC is preferred, compartmentalization of *beel*s into culture ponds should be discouraged. This is against the norms of eco-friendly development and will lead to elimination of the biodiversity. Digging of culture ponds should be encouraged only in swamps and other low lying areas – but not in the main body of beel.

Indigenous fishes

It is not necessary to develop all *beels,* as carp-based fisheries. Due to habitat loss on account of developmental activities, the natural stock of indigenous fish populations are on the decline. *Anabas testudineus, Clarias batrachus, Ompok* spp., murrels, *Amblypharyngodon mola, Puntius* spp, are a few among them. Since floodplain wetlands are the last refuge for these species, it will not be wise to convert all the *beel*s into carp systems. It will be worthwhile to develop enhancement systems employing local species by retaining the habitat. This may mean a lower yield rate compared to carp enhancement but the price difference in favour of indigenous species will compensate for the low yield rate and the environmental and biodiversity gains can be considered as bonus. This practice will also prevent the compartmentalization of *beels* and their conversion into ponds.

Exotic fishes

Exotic fishes should be discouraged for species enhancement as the *beel*s are contiguous with our river systems. Exotic fishes ,if gained entry into our river systems, can adversely affect the indigenous fish fauna due to competition for food and breeding space. India with one of the richest fish germplasm resources in the world can ill afford such a loss.

OTHER FORMS OF ENAHNCEMENT

Fishery based on pen and cage culture

Many of the beels 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 *beels.* This solves the problems created by gear restrictions and catchability. This mode of enhancement has been proved to be a boon in the beel management in West Bengal.

Integrated approach

Beels also can be part of an integrated system including navigation, bird sanctuary, post harvest, aquaculture and open water fisheries. A scheme designed for a closed *beel* in 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. In this example, 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. Pathways of energy flow in (Macrophyte-Detritus chain)

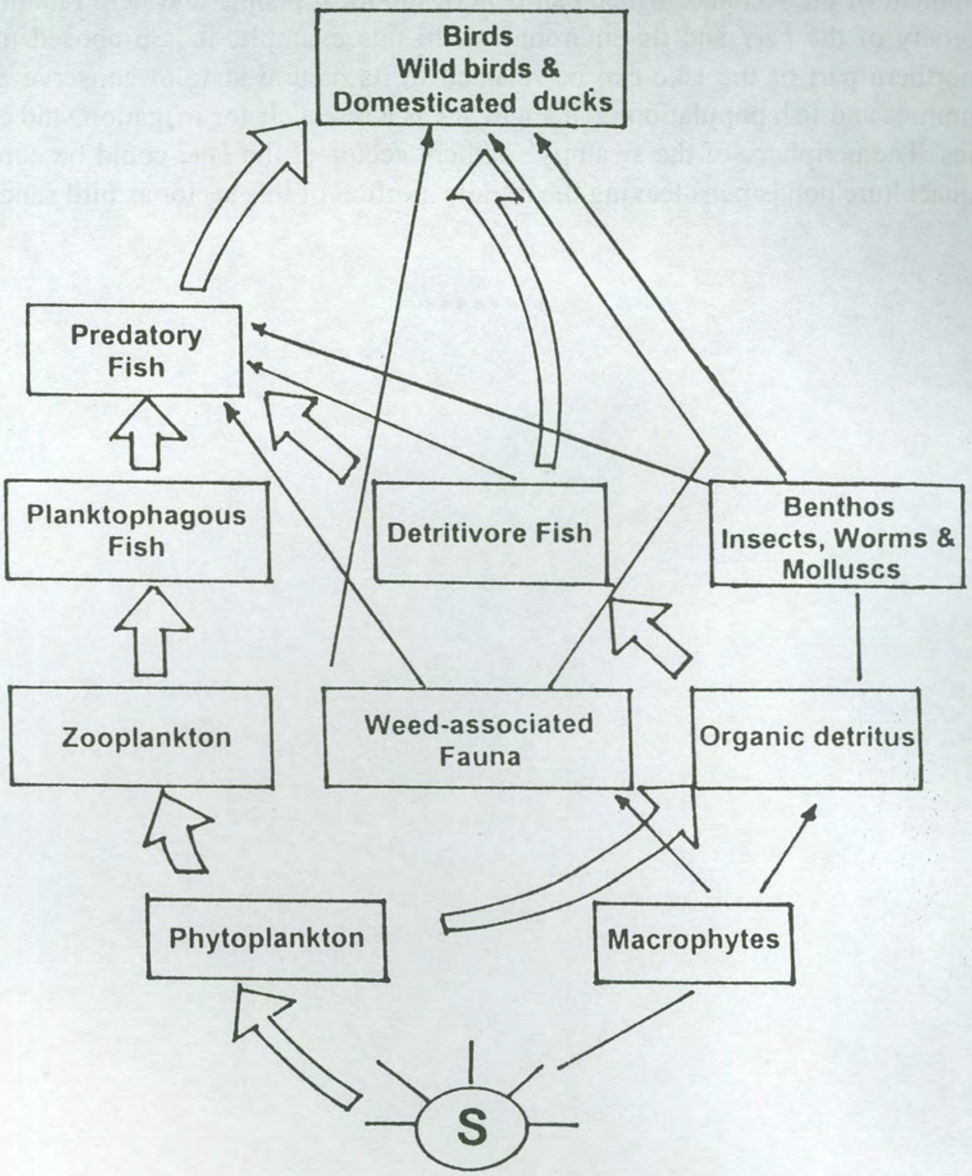


Fig. 2. Pathways of energy flow in (Grazing chain)

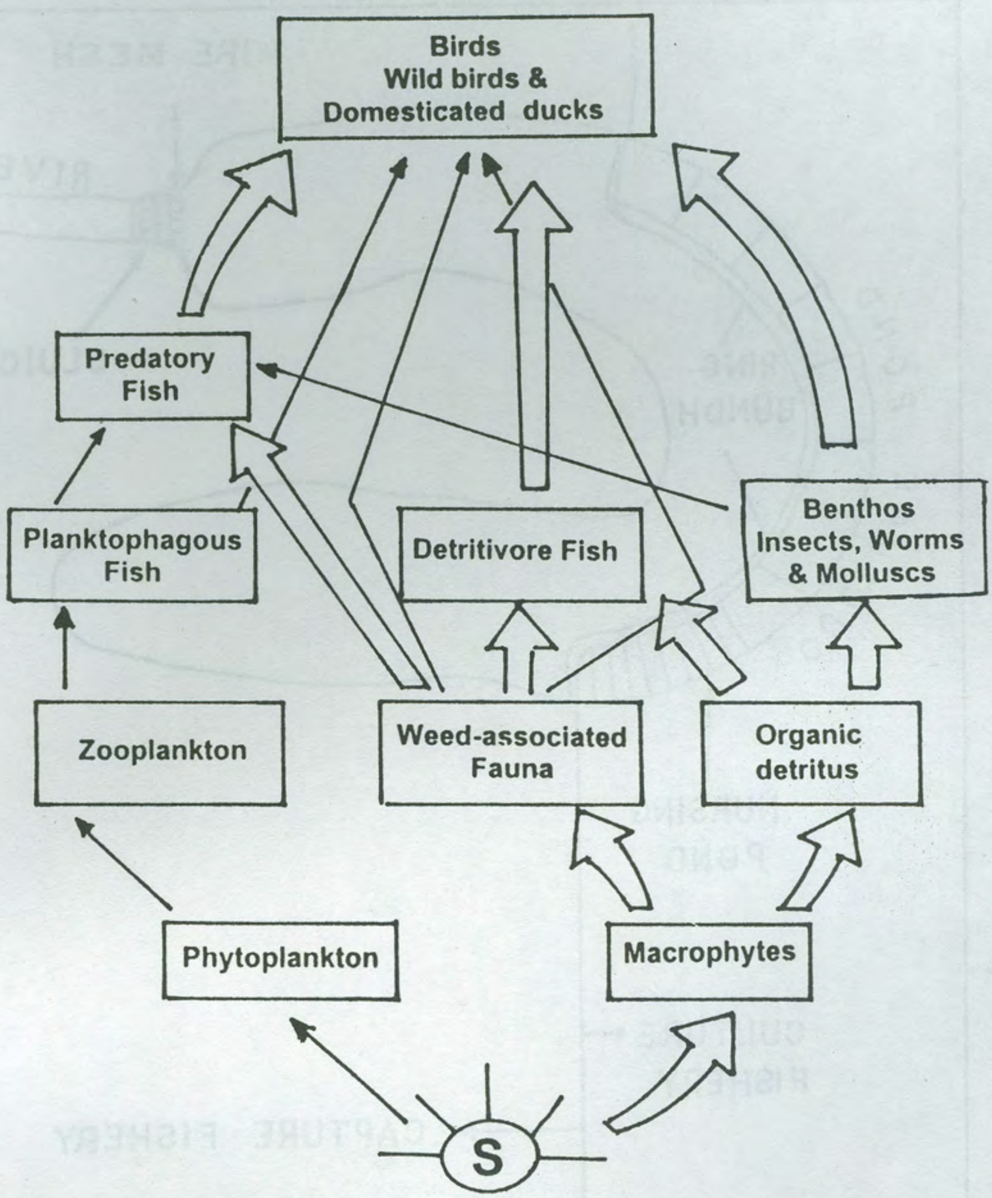


Fig. 3. **Diagrammatic representation of culture and capture fisheries development in Assam**

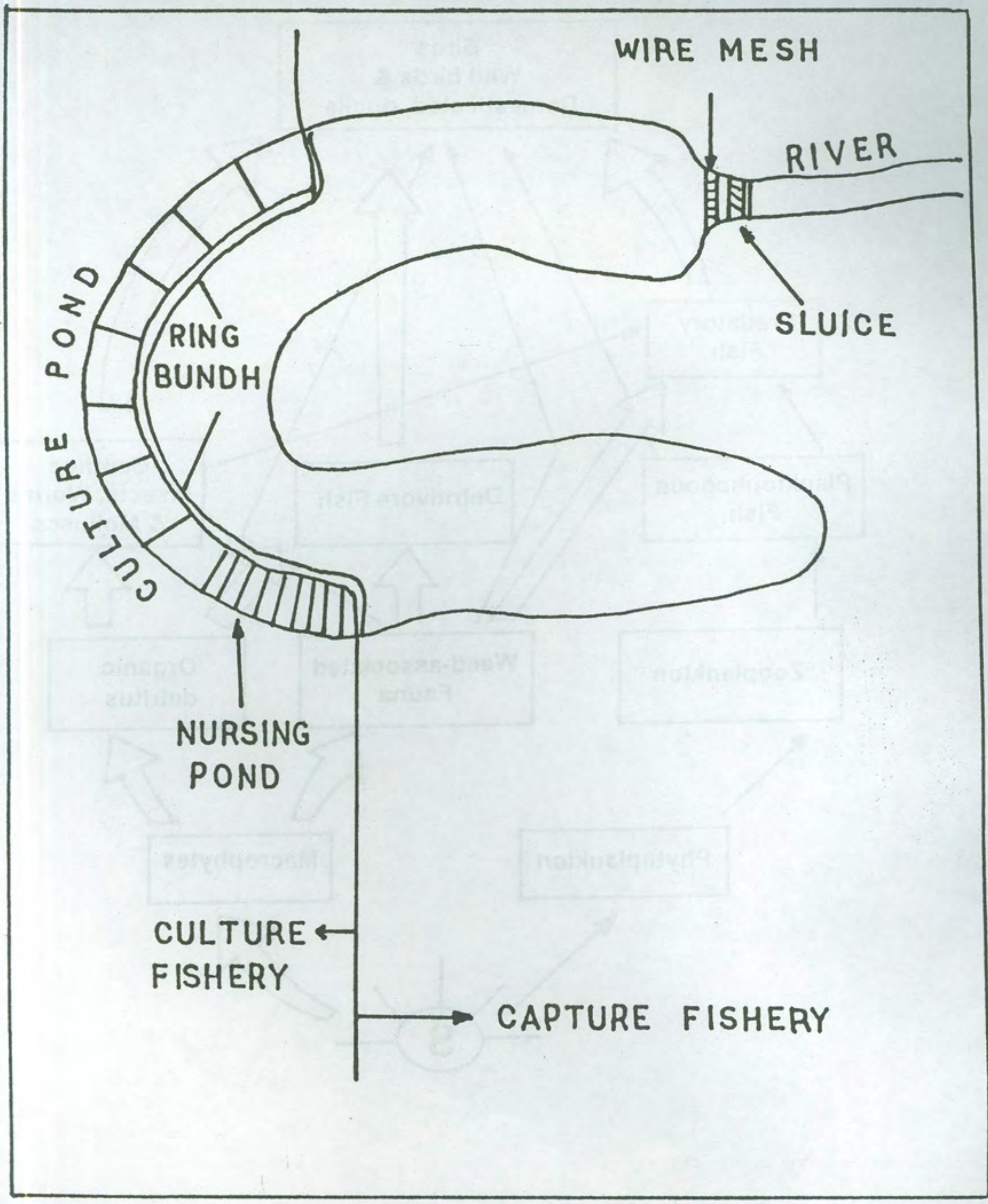
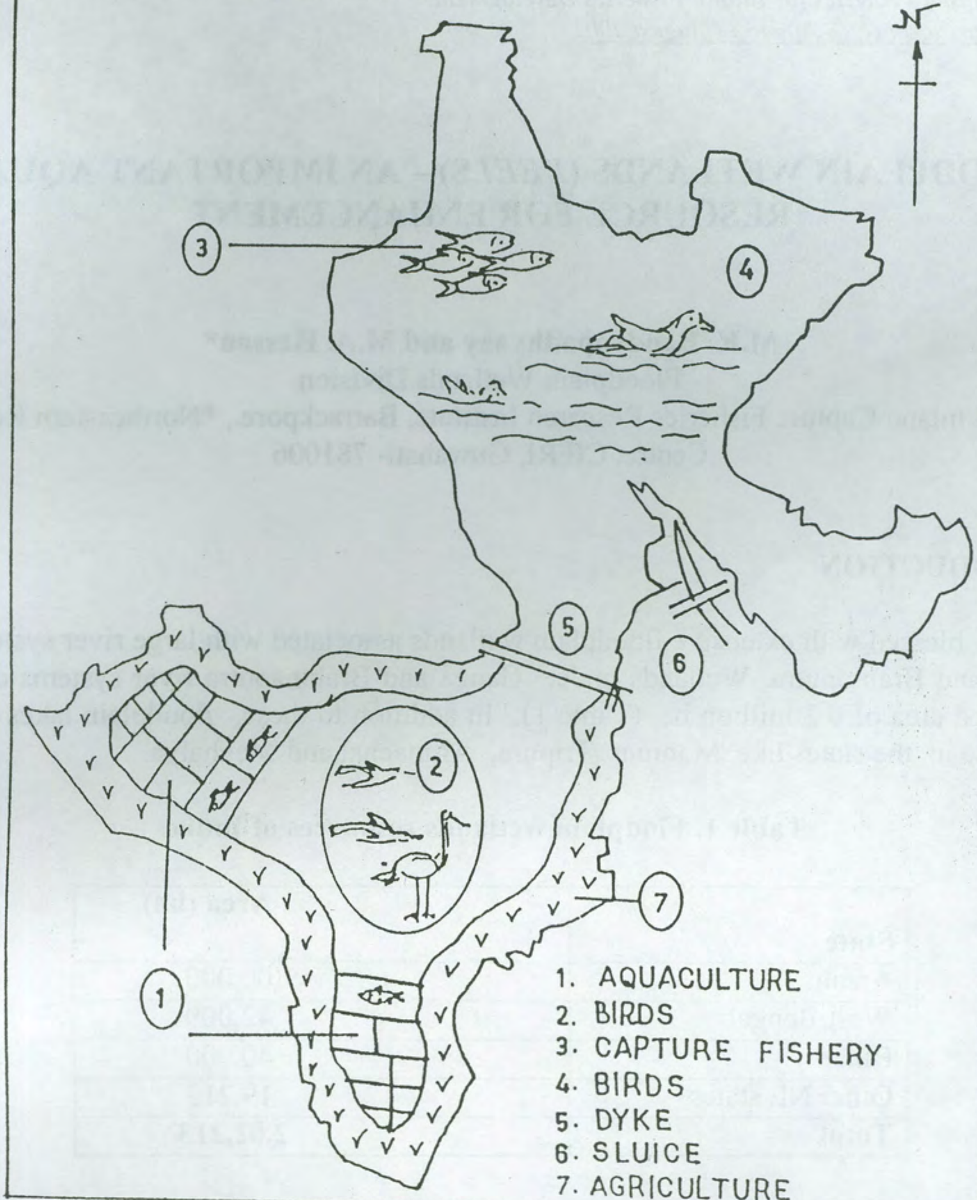


Fig. 4. Integrated Development of Beel



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FLOODPLAIN WETLANDS (*BEELS*) – AN IMPORTANT AQUATIC RESOURCE FOR ENHANCEMENT

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INTRODUCTION

India is blessed with extensive floodplain wetlands associated with large river systems like Ganga and Brahmputra. Wetlands under Ganga and Brahmaputra river systems cover an estimated area of 0.2 million ha. (Table 1). In addition to these, floodplain lakes are also available in the states like Manipur, Tripura, Arunachal and Meghalya.

Table 1. Flodplain wetlands resources of India

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

According to their origin, wetlands are categorized into ox-bow lakes, sloughs, meander scroll depressions, backswamps, residual channels or tectonic depressions. These water bodies are locally called *beels* (Assam, West Bengal, Arunachal Pradesh, Meghalaya and Tripura). *maun*, *chaurs* and d*har*s (Bihar), *pats* (Manipur) *chars* and *baors* (northern and south eastern West Bengal). Floodplain wetlands form a very important fishery resource and source of livelihood for thousands of poor fishermen.

Peculiar ecological features of wetlands such as variable hydrodynamics, morphometry, nutrient profile, weed infestation, transparency, heavy load of organic matter and high photosynthetic efficiency offer ideal environment for a large variety of ichthyofauna due to the availability of ample feeding and breeding grounds, shelter from predators, suitable nursery and rearing ground.

WETLANDS - HIGHLY PRODUCTIVE ECOSYSTEMS

Morphometry

Morphometric features like water levels, depth, water discharge (in- and outflow) and shore development influence production process to a great extent. Shallow depth, protracted littoral zone, gradual slope of the basin and irregular shoreline are highly favourable from productivity point of view. Limnologically, productivity of any water body is inversely related to its depth.

Transparency

Penetration of sunlight in a water body has a direct bearing on productivity mechanism. Contrary to pond ecosystem, light penetration to a greater depth in wetlands is proved to be beneficial in the sense that the energy flow in this case is through *macrophyte-detritus* food chain. Therefore, transparency, when combined with shallow depth, results in luxuriant growth of primary producers in the form of aquatic macrophytes which, on decay, is transformed into detritus - an important link in the food chain of wetland.

Favourable water and soil quality parameters

Fish yield potential of any water body is determined generally by the intricate interaction of various biotic and abiotic factors including climatic, edaphic and morphometric features. The climatic factors like temperature, wind action and rainfall have great influence on the production mechanism of any ecosystem. The irradiance pattern and duration directly influence energy trapping mechanism. The basic soil and water quality parameters of wetlands are given in Table 2 and 3.

Table 2. Ranges of soil quality of beels

Parameter	Values (ranges)
pH	5.9-7.8
Soil composition	
Sand (%)	74-93
Silt (%)	3-14
Clay (%)	4-20
Sp. Conductivity (μmhos/cm)	220-1100
Total nitrogen (mg/l)	0.09-0.60
C-N ratio	8-13

Table 3. Ranges of water quality parameters of *beels*

Parameter	Values (ranges)
Water temperature (^{o} C)	22-34
Water transparency (cm)	55-268
pH	7.6-8.2
Dissolved oxygen (mg/l)	5.2-11.4
Alkalinity (mg/l)	12.8-174
Conductivity (μmhos/cm)	221-357
Phosphate – P (mg/l)	Tr. – 0.06
Nitrate – N (mg/l)	0.10-0.28

The soil and water quality parameters of wetlands vary within favourable range f or high fish yield. For instance alkaline pH, sufficient dissolved oxygen, abundant plant nutrients as indicated by high specific conductivity are all indicators of a productive aquatic environment. Except the wetlands in Assam, the soil reaction is generally alkaline in nature indicating good productivity potential of the system.

AQUATIC HIGHER PLANTS, PRODUCTIVITY AND FISHERIES

Aquatic plants form the integral part of wetlands ecosystem. Presence of macrophytes in a wetland gives them a multidimensional scope for sustenance of large variety of fish species, which are attracted here for feeding, breeding and taking shelter. In addition, macrophytes being chlorophyll bearing, act as the prime agent of trapping solar energy. Dense mass of these higher aquatic plants prevents the growth of other chlorophyll bearing plants, hence their role in the food chain of wetlands ecosystem becomes rather negative. Studies reveal that plankton density exhibits an inverse relationship with macrophyte biomass.

Ironicaly, none of the fishes found in the wetlands directly make use of this primary source of energy. Macrophytes enter the food chain when they die and form detritus. This offers an opportunity to encourage fishes with shorter food chain, particularly detritivorous fishes, leading to maximisation of photosynthetic efficiency by converting primary energy reserves into harvestable materials.

HYDRODYNAMICS

Changing patterns of water retaining capacity of wetlands during various seasons give ample scope for enhanced production of fishes. During monsoon the *beels* resume connection with the parent rivers converting them into a fluviatile ecosystem which facilitates autostocking, loading with allochthonous organic matter, recharging of nutrients and removal of harmful metabolites. On the other hand, during post-monsoon the system looses its connectivity with parent river, transforming them into an altogether different ecosystem and the environment thus created lasts till the onset of next monsoon. It is at this point that management interventions in the form of fish stock manipulation can be taken up in order to reap a good harvest and optimal utilization of this resource.

ENHANCEMENT PROGRAMME

Despite all the desirable characteristics, featuring the wetlands, we could not yet harness the full fish production of these water bodies. Well planned, location-specific enhancement programmes are required to tackle the problem of low productivity.

The ecological features of floodplain wetlands offer immense scope as observed in the foregone discussion, for implementing fisheries enhancement programmes. 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, alteration of the exploitation norms, modifications or regulation of craft and gear, intervention in management norms and so on. The enhancement norms, which are pertinent to floodplain wetlands, can be grouped as :-

1) stock enhancement
2) species enhancement
3) environmental enhancement
4) management of craft and gear
5) management through new culture system like cage and pen culture

Stock enhancement

Survey of natural fish fauna in wetlands reveals that the diversified niche of this peculiar ecosystem are not being fully being utilised suggesting scope for intervention in the form of stock augmentation. Augmenting the stock will provide two pronged advantages. First, stocking with suitable species in sufficient number will fill the gap of unutilised niche. Secondly, the stocking will prevent the overlapping of niche by undesirable species. As noted earlier, wetlands are the biggest reserve of both allochthonous and autochthonous detritus, among freshwater resources. Variety of detritivore fishes in large numbers (to suit the carrying capacity) can be accommodated in such system. In addition, the presence of abundant macrophyte associated fauna (worms,insects and snails) provides the opportunity to stock fishes which can utilise these food sourçes. Stock enhancement, therefore, requires careful selection of species, determination of stocking density and size of stocking material. A relatively bigger size stocking material is to be opted to prevent loss due to predation.

The topography of wetlands also favours the rearing of stocking material in the gentle slope of their basin. The marginal areas are excellent place for developing into nursery and rearing ponds where stocking materials (advanced fingerlings) can be made ready for releasing into the main water body.

Species enhancement

Enhancing the spectrum of fishes by introducing new species can be an effective means of increasing fish production. Wetland ecosystems of India do not harbour any native phytophagus species of fish which otherwise could have utilised the aquatic macrophytes available in plenty. So, there is ample room for the introduction of species like *Ctenopharyngodon idella* and *Puntius javanicus* for ready consumption of this food source. In addition, stocking of detritivore species like *Labeo gonius* , *Cirrhinus reba* and *Cyprinus carpio* can be thought of for effective utilisation of the enormous reserve of detritus. Mollusc eating fishes like *Pangasius pangasius* can be considered to make best use of snail population that grows in association with aquatic macrophytes.

Management enhancement

In addition to the traditional use of wetlands as fisheries resource, the management can be diversified to generate more income from this resource. Diversification like sport fishing, encouragement of migratory birds to inhabit the wetlands which will increase the fertility through their excreta and will attract tourists. Sport fishing and improvement of fertility will obviously help in enhancing fish production from these resources.

Regulation of craft and gear

Strict vigil is warranted on the use of craft and gear to be used in wetlands. Wetlands are natural breeding and nursery grounds of several riverine fish species. With a view to enhancing fish production from wetlands, brooders should be allowed to enter their breeding ground during their breeding migration. Similarly, the use of mosquito nets to catch smallest possible fishes should be strictly prevented to allow self stocking of the wetlands. This will not only give fillip to fish production but also will save several valuable and vulnerable wetland species from extinction.

Management through new culture system

To intensify fish production from wetlands, adoption of new culture system is a relevant option. In addition to above mentioned enhancement programme, the wetland throws open opportunities for furtherance of fish production through new system of fish culture in pen and cage enclosure. In macrophyte choked wetlands, rearing of fish either for seed or table size production in the marginal areas can be practised for augmenting fish production.

CONCLUSION

In view of the vastness and potentialities of wetlands, the importance and need of the means and ways to harness these resources has been greatly realised. Scientific development based on principles of enhancement programme would largely add to the quantum of harvest from the wetlands. In addition to this, institutional support with target oriented government plan, organised cooperative movement associated with constant pursuance of scientific endeavour and active people's participation would definitely lead of successful fisheries development in wetlands.

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FISHERIES DEVELOPMENT OF ESTUARINE WETLANDS IN WEST BENGAL

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INTRODUCTION

The vast low-lying wetlands situated in the east of Kolkata City constitute an important fishery resource of West Bengal. Spread over about 42,600 hectares, these wetlands belong to diverse ecotypes. Freshwater sewage-fed wetlands situated in the Kolkata spill area in the bed of the defunct Vidyadhari river are extensively used for growing freshwater fishes. The wetlands situated below the Kulti lock gate which have salinity of different magnitudes, are accordingly classified as low, medium and high saline. These freshwater and saline wetlands situated in the North and South-24 Parganas districts of West Bengal contribute substantially to the total fish production of the state. Traditional culture practices are adopted for growing various species of fish and prawn in these wetlands by the farmers and there is immense scope for further enhancing the production and yield from these water bodies by introducing proper scientific management practices. These wetlands, locally known as *bheri*es, are large shallow water bodies embanked by earthen dykes in which the water depth seldom exceeds 1 m. The *bhery* fishery provides employment for a large number of rural people who are directly and indirectly involved in fishery and related activities.

TYPES OF ESTUARINE WETLANDS

The *bheri*es can broadly be classified as (1) Freshwater and (2) Saline

Freshwater bheries :

In the eastern outskirts of Kolkata city there exists a vast natural spill area covering about 4000 ha. The wetlands situated in this low lying area receive city sewage and are examples of very low cost sewage utilization systems resulting in production of a huge quantity of aquacrop in the form of fish and prawn. The freshwater sewage-fed *bheri*es receive strong, moderately diluted, or diluted sewage.

Saline *bheries*

Depending upon the water salinity the saline wetlands are classified as:

1. Low saline(<10 ppt)
2. Medium saline (10-20 ppt)
3. High saline(> 20 ppt)

There has been considerable changes in the ecology of these water bodies particularly in terms of salinity during the last 15 years and the salinity zones are now required to be freshly categorized as per the changed salinity regime. Some of the wetlands in the low and medium saline zones (Macchibhanga, Haroa and Minakhan area) receive diluted sewage mixed saline water and may therefore, be categorized as saline sewage-fed wetands.

ECOLOGY OF WETLANDS

Freshwater Wetlands

In the freshwater sewage-fed wetlands, the DO ranges from 2.6 and 10.5 ppm during the early hours of the day. In the wetlands receiving strong or moderately strong sewage, the DO may go up as high as 16-20 ppm in the midday and traces-nil in the midnight. All these wetlands have salinities ranging from traces-1.2 ppt. The total alkalinity of water ranges between 80 and 320 ppm.The primary production in these water bodies ranges from 280- 1800 mgC/m/hr. The freshwater wetlands are rich in nutrients like NO_3, and PO_4P.

The plankton concentration in these wetlands varies from 0.15 to 3.5 ml/50 l. However, in wetlands receiving dilute sewage, the plankton concentration is generally much lower. The principal zooplanktonic forms encountered are *Cyclops* sp., nauplii of copepods, *Brachionus* sp., *Keratella* sp., *Filinia* sp., *Moina* sp., *Bosmina* sp.,etc. The important phytoplanktonic forms encountered are *Scenedesmus* sp., *Pediastrum* sp., *Spirogyra* sp., *Lyngbya* sp., *Oscillatoria* sp., *Anabaena* sp., *Merismopedia* sp., *Microcystis* sp., *Coscinodiscus* sp., *Synedra* sp., *Pinnularia* sp., etc. There is an over all dominance of Myxophyceae in this region.

Macrozoobenthic fauna in these wetlands is constituted mainly of chironomid and other depteran larvae, odonate nymphs, gastropods, (*Bellamya* sp., *Thiara* sp., *Lymnaea* sp., *Indoplanorbis* sp.) bivalves and sometimes annelids.

Saline wetlands

The salinity of water in the low saline wetlands ranges between 0.21-10.49 ppt as observed during 1999-2001. The mean value of salinity has decreased considerably compared to that of 1986. The salinities of the medium and high saline zones ranged from 0.21-14.43 and 1.84 -24.95 ppt in some wetlands studied recently. The salinity in some of the high saline *bheries* even exceeds 33 ppt. In recent times the annual mean values of salinity have been observed to be 1.61 ppt to around 3.0 ppt in the low saline zone, around 3.0- 5.0 ppt in the medium saline zone and around 12-13 ppt in the high saline zone. The total alkalinity in the saline wetlands remains within the normal range and is generally found to be the highest in the high saline zone. PO_4P and NO_3N contents have been found to be higher in the low and medium saline bheries studied recently but higher phosphate values are generally obtained from high saline *bheries*. Primary productivity has also been observed to be higher in the low saline zone. The pH of water ranges from 7.16-9.01. DO in all the *bheries* is conducive for pisciculture. The free CO_2 is generally found to range between nil and 48 ppm in different wetlands.

The bottom soils of the saline wetlands have pH ranging from 7.6-8.7. Electrical conductivity is the highest in the high saline zone and lowest in the low saline zone. However, available nitrogen is found to be the highest in the low saline zone and so also the available P.

The plankton concentrations in the saline *bheries* are generally lower than the freshwater zone. In all the three zones the zooplankters have an overall dominance over phytoplankters. *Brachionus* sp., *Keratella* sp., *Filinia* sp., *Polyarthra* sp., *Cyclops* sp., *Diaptomus* sp., nauplii of copepods, *Daphnia* sp., *Moina* sp., *Bosmina* sp., mysids *etc.* are the principal forms of zooplankters encountered. *Oscillatoria sp., Lyngbya sp., Anabaena* sp., *Spirulina* sp., *Spirogyra* sp., *Scenedesmus* sp., *Chlorella* sp., *Nitzschia* sp., *Gyrosigma* sp., *Coscinodiscus* sp., *Navicula* sp., *Synedra* sp., *Pinnularia* sp.,etc. are the principal forms of phytoplankters found in different zones. In these zones Myxophyceae and Bacillariophyceae have edge over the Chlorophyceae.

The macro-zoobenthos comprises tanaids, amphipods, molluscs(mostly gastropods), polychaetes and insect larvae (mostly dipterans) in the saline region as a whole.

FISH AND PRAWN CULTURED IN DIFFERENT WETLAND SYSTEMS

Fresh water wetlands

Species cultured

In freshwater *bheries* Indian major carps, exotic carps (*Hypophthalmichthys molitrix* and *Cyprinus carpio*) together with tilapias (*Oreochromis niloticus* and *O. mossambicus)* and *Labeo bata* are reared at a combined stocking density of 45,000-50,000/ha. In recent years, some farmers grow the giant freshwater prawn *Macrobrachium rosenbergii* though not in a very organized manner. Scientists of CIFRI could achieve success in rearing the giant prawn in a moderately diluted sewage-fed wetland. Miscellaneous species of fishes like, *Mystus gulio, Glossogobius giuris* and *Puntius* sp. are also encountered in freshwater sewage-fed water bodies.

Culture methods

Sewage from the main sewage canal passes through narrower canals before being drawn into the wetlands through wooden sluices by regulating the flow of water at the entry point so that only the supernatent portion of the effluent is drawn into the *bhery*. Fifteen to 25% of water is exchanged every fortnight (or some times every month). At the initial phase, the sewage water after being drawn is allowed to stand for a few days till the BOD is reduced and algal bloom appears. Algal bloom results in photo-synthetic activity and the BOD is further reduced. These wetlands are generally shallow having water depth ranging from 50 cm to 1 m. The wetlands are stocked heavily with Indian major carps, exotic carps, minor carps and tilapias. There is, however, always some autostocking of tilapias since it is not possible for the farmers to completely drain out the water and dry up the bottom every year. Initially the rearing is done for a period of 3 - 4 months and harvesting is done when the fishes grow to 150 - 350 g. Table size fishes above 500 g are rarely encountered in the catch. The culture system in the *bheries* can be called a "continuous stocking and harvesting system" in which the stock is continuously being replenished after harvesting. This may however, lead to undesirably high stocking densities, sometimes even exceeding 50,000/ha which may affect the growth of the stocked fishes. Some of the farmers have started giant prawn farming in this area making provision for feed and aeration. Whenever required, the wetlands are drained out by the outlet(s) and required amount of water is drawn in through the inlet.

Saline bheries

Species cultured

The tiger shrimp, *Penaeus monodon,* and the mullet *Liza parsia* are the most important prawn and fish species reared in the low and medium saline wetlands. The tilapias *O. niloticus* and *O. mossambicus* are also important components of the stocked fish. The giant perch *Lates calcarifer* is not stocked generally but they enter the *bheries* along with ingress water. Presence of *Lates calcarifer, Glossogobius giuris, etc.* may cause heavy depletion to the prawn and fish stock due to predation. In many low and medium saline wetlands, carp culture is taken up after the monsoon precipitation to make use of the freshwater conditions. During this phase, major and minor carps (particularly *Labeo bata*) are reared. Recently, some farmers are practising freshwater giant prawn culture during this period. Scientists of CIFRI have successfully demonstrated the rearing possibility of *M. rosenbergii* in medium saline wetlands where almost freshwater condition exists following monsoon precipitation.

In medium saline wetlands, *G. giuris, Mystus gulio, Gobioides rubicundus, etc.* are also encountered. Some smaller species of penaeid prawns are usually present in these water bodies which enter into the system through incoming water.

In the high saline zone, besides autostocking (seeds entering with the ingress water) selective stocking is done with *P. monodon, Liza parsia* and *Liza tade.* In these wetlands tilapias are also grown along with other species of fishes and prawns. *Mystus gulio* is also found in good numbers along with some species of penaeid prawns.

Culture methods

The tidal water from rivers or tributaries are drawn into the *bheries* during full or newmoon days when the amplitude of the tide is high. The ingress water enters through the inlet which is guarded by thick meshed nets to prevent entry of larger carnivorous fishes. A sluice box is fitted at the inlet. In the saline *bheries*, generally the inlet and outlet points are the one and the same. In larger *bheries,* the inlet-outlet channels are more to facilitate quick filling and draining of water. The draining of water is done during low tide. Though the exchange of water is normally done fortnightly, sometimes the water is retained for longer period of one to two months. The water exchange is necessary to keep the environment conducive for the cultivated fishes and prawns besides providing a continuous source of natural food. Previously, most of the *bheries* were used to be autostocked but now-a-days, many in low and medium saline zones are selectively stocked. Even the wetlands in the high saline zones are now practising selective stocking in addition to natural stocking. In medium and high saline zones, tilapias are stocked normally inspite of the fact that both the species of tilapias *O. niloticus* and *O. mossambicus* have been observed to breed in these zones. In medium and low saline zones, *O. niloticus* is preferred as a stocking material while in the high saline zone *O. mossambicus* is preferred.

PRODUCTION FROM WETLAND SYSTEMS

In the freshwater sewage-fed wetlands, the yield varies from 5,000-10,000 kg/ha/yr or a little more in case of strong sewage enriched ones, 4,000-6,000 kg/ha/yr in case of moderately strong sewage enriched wetlands and 2,000-3,000 kg/ha/y in case of diluted sewage enriched *bheries*. In the saline region, the medium saline zone had higher production compared to other two zones. However, recent studies conducted in some *bheries* in the three zones recorded that the production in the low saline zone *bheries* as higher compared to medium and high saline zones. This may be attributed to the introduction of large-scale carp culture in the low saline wetlands. However, *P. monodon* production is highest in the medium saline zone compared to those of the low and high saline wetlands. Recent studies show that the production from saline wetlands has dwindled to a little extent compared to the past. One of the reasons for low production of tiger shrimp in the wetlands was due to white spot disease which caused heavy damage to the monodon crop.

SCOPE FOR FURTHER DEVELOPMENT

There is immense scope for further enhancing production from estuarine wetlands. The production from some of the wetlands have gone down in recent years. Some of the management measures which can be adopted to augment production from wetlands are listed below:

1. The bottom soils of the wetlands should be excavated at least every three years so as to remove the accumulated muck at the bottom which may hinder production.

2. Some of the wetlands particularly in the freshwater and low saline zones, have heavy infestations of molluscs which create problem to the culture of fishes and prawns. In these wetlands *Pangasius* sp. may be introduced.

3. Since tilapia is a prolific breeder, heavy recruitment and resultant competition for food leads to low growth rate of tilapia in the wetland. This could be overcome by following mixed culture of tilapia with *Lates calcarifer* where *Lates* can control the excess population of tilapia. In this mixed culture, good production can be expected for both the species.

4. The giant freshwater prawn *Macrobrachium rosenbergii* may be introduced in freshwater and low/medium saline wetlands.

5. Carp culture may be taken up in the medium saline zone during monsoon and early post monsoon period.

6. Regular monitoring of the water bodies is the prime prerequisite for maintaining water quality which will not only help boosting production but will also help in preventing disease infestations.

7. Pen and cage culture can be tried.

8. Adoption of rice fish culture system in low and medium saline wetlands, with or without sewage influence, may help getting higher yields from such ecosystems.

9. People involved in wetland fisheries should be given proper training with regard to scientific management practices so that they may tackle some problems themselves as and when such problems arise.

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PEN CULTURE-AN EFFECTIVE TOOL IN FISH YIELD OPTIMIZATION IN FLOODPLAIN WETLANDS

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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, chaur, beels, jheel* 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 decides 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, maun* or shallow impoundments. The bamboo for making frame should be of 6" to 8" in diameter and 30' 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 exit 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 quicklime @ 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 maintainedfor 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 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 desirableparameters 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 been proved to be successful. However, from economic point of view, monoculture of giant freshwater prawn ismore 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%) (Silver carp, 15%)	-	35%
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 densitycould 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 pelletized 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. Rapidand haphazard development of fish pens, converted the lake from a lucrative fishery into a battery of pens reducingthe open water fishing area. This also caused unemployment for traditional fishers. Supplementary feeding of the stock 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. 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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FISH HEALTH MANAGEMENT IN CULTURE-BASED FISHERIES

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INTRODUCTION

The stability of a fish population in a particular habitat is very often disrupted by various factors *viz.,* disease, habitat destruction, depletion of resources, or the application of other environmental stressors. Fish is in a state of equilibrium with the environment and a change in the environmental parameters beyond the tolerance limit disturbs this equilibrium resulting in stress response in fish and making it vulnerable to diseases.

In culture based fisheries development in *beel*s, *bheri*es or small reservoirs, the affects of adverse environmental conditions or the effects of culture procedures have a profound impact on the health status of the resident fish population. The succeeding pages will elaborate on the water quality parameters of importance, the stress being created and the various fish diseases being encountered in these ecosystems.

Environmental parameters of importance in relation to fish health

Oxygen

Often fishes swim on the surface of water gulping air with mouth wide open. This stressed condition of fish is due to oxygen depletion in water. Three main factors influence the amount of oxygen which a water body can hold.

a) Temperature - water holds less oxygen at higher temperature.
b) Salinity - water holds less oxygen at higher salinities.
c) Atmospheric pressure - Water holds less oxygen at low atmospheric pressure. Other factors which affect the amount of DO in water include phytoplankton blooms, organic loading and respiration of fish and other aquatic vertebrates and animals.

Ammonia

It is commonly the second important parameter after DO. The total ammonia concentration in water consists of two forms.

NH_3 - unionised ammonia
NH_4 - ionised ammonia

The unionised fraction is most toxic to fish. As a general rule, higher the pH and temperature, higher the percentage of total ammonia *i.e.,* the toxic unionised form. Ammonia in water originates from :

i) decomposing organic matter
ii) excretion by aquatic organisms
iii) death and break down of blooming phytoplankton

Hydrogen sulphide

Very often the muck in the sediments smell like rotten eggs and the bottom dwelling fishes surface and die. This is due to accumulation of H_2S gas which is produced by chemical reduction of organic matter.

Nitrite

Fish gills frequently turn brick red in colour, due to the presence of excess nitrite in excess water, which is absorbed by fish and reacts with haemoglobin to form methaemoglobin giving brick red colour to the gills.

Suspended solids

It originates from phytoplankton blooms, uneaten food particles and fish faecal matter. Suspended solids are responsible for reducing the penetration of light thus decreasing productivity.

pH

It is an important parameter affecting fish health. The optimum range of pH for most of the freshwater fishes is 6-9. The factors which affect the toxicity of acid to fish are

CO_2 - high CO_2 increases the toxicity of acid *CO_2*

Free CO_2 is toxic to fish. High concentration (12-50 mg/l) of free CO_2 hinders uptake of DO by fish. The effects of high CO_2 are accentuated at low DO concentrations.

ALKALINITY

Water with low alkalinity, less than 20 mg/l, have low buffering capacity and consequently are very vulnerable to fluctuations in pH due to rainfal or phytoplankton bloom.

SPECIFIC CASE STUDIES ON WATER QUALITY AND ITS INFLUENCE ON FISH HEALTH

Sewage-fed wetlands (bheries)

Six sewage-fed wetlands ranging from 25-40 ha in Haroa (North 24-Parganas) were investigated (Das, 1999). They receive Calcutta Municipal sewage along with tidal water ingress and fish and prawn were cultured. The physico-chemical properties of these bheries are given in Table 1. All the *bheries* are characterised by low transparency and consistently high levels of unionised, ammonia, the factors responsible for creating stress to fish. Moreover, the high microbial consumption of dissolved oxygen (1.8 mg/l/h) indicates exhaution of DO for a few hours at night creating stressed condition for fish. This observation is in close agreement with the water quality profile recorded in the sewage-fed freshwater wetlands in east Calcutta (Das *et al.,* 1994). Here too, the high microbial consumption of DO, high unionised ammonia and low transparency were the prime stress factors for fish. As a result the average fish yield from these wetlands ranged within 2,000-2,500 kg/ha

FRESHWATER WETLAND (BEEL)

Garapota a typical open beel with 40% macrophyte infestation was investigated (Das, 1999). The range of water quality parameters during a year and diurnal variation of some important chemical parameters are given in Table 2. The diel variation of the chemical parameters indicate dissolved oxygen as the important stress factor. The DO level is reduced to nearly 3.5 mg/l around 2200 hrs. at night and remain below this level for more than 8 hours causing stress to resident fish population. Unionised ammonia recorded in the range of 0.05 to 0.25 mg/l is also acting as a stress factor. As a result the normal growth of fish has been affected and the average yield from this beel was 550 kg/ha. The results obtained has similarity with the ecological status of the various beels in West Bengal, Assam and Bihar which are mostly in various stages of eutrophication and choked with submerged or floating vegetation and suboptimal water quality (Sugunan & Bhattacharya, 2000). As a result, the average yield from these wetlands ranges between 120-300 kg ha^{-1} against the potential yield of 1000-1500 kg/ha.

Table 1. Environmental parameters of sewage-fed wetlands investigated (average values)

	Maligada bheri	*Beel Samity*	*Kathore bheri*	*Tripley bheri*	*Agamura bheri*	*Barachak bheri*
Transparency (cm)	17	21	15	18	25	20
pH	8.6	8.5	8.6	9.0	8.3	8.3
Alkalinity mg/l	125	126	127	147	127	114
Hardness mg/l	3000	3000	2800	3200	11000	2300
Unionised ammonia mg/l	1.1	0.5	0.3	0.2	0.1	0.4
Salinity	9.0	10.2	6.4	7.0	9.0	10.0
Microbial O_2 consumption mg/l	-	1.8	-	-	-	-

Table 2. Physico-chemical characteristics of Garapota beel

	Range of water quality parameters during year	Diurnal variation of water quality parameters											
		10 AM	*12 Pm*	*2 PM*	*4 PM*	*6 PM*	*8 PM*	*10 PM*	*12 PM*	*2 AM*	*4 AM*	*6 AM*	*8 AM*
Temperature (water)	26-36	22.5	24.0	24.5	24.0	22.0	21.0	21.5	20.5	20.5	21.5	22	22.5
Alkalinity (mg/l)	133-212	212	214	201	206	214	209	212	210	209	210	215	210
Hardness (mg/l)	120-199	195	199	187	190	193	195	198	198	190	197	199	196
Unionised ammonia (mg/l)	0.05-0.25	0.1	0.1	0.1	0.15	0.11	0.1	0.1	0.2	0.1	0.1	0.1	0.1
CO_2 (mg/l)	1.0-8.0	1.0	1.0	1.0	1.0	1.5	1.0	1.5	2.0	2.0	2.0	1.5	1.0
Chloride (mg/l)	3.7-9.5	7.5	7.0	7.8	6.9	7.2	7.5	7.5	7.3	7.4	7.9	7.8	7.0
DO (mg/l)	6.0-9.0	6.5	8.0	9.0	9.0	7.5	5.2	3.5	3.0	2.0	2.0	2.0	3.0
pH	7.8-8.0	8.0	8.0	8.1	8.0	8.0	8.0	7.9	7.9	8.0	7.8	8.0	8.0

Fish diseases commonly encountered

Sewage-fed bheries

The details of the fish diseases commonly encountered in sewage-fed bheries and their causative agents are given in Table 3 (Das, *et al*, 1994).

Table 3. Fish diseases recorded in Kantatala sewage fed wetland

Sl. No.	Disease	Host	% incidence	Symptoms	Causative agent
1.	Gas bubble disease	*C.mrigala* (10-40 gms)	15	Bulged abdomen. Gas accumulated in intestine. Die whirling	Anaerobic condition produce small bubbles; gulped by fish
2.	White scale spot disease	*C.mrigala* *(20-90 gms)*	10	Scales fall of with ulceration	*Myxobolus indicum* *M.mrigalae*
3.	White gill spot disease	*Catla catla* (25-90 gms) *C.mrigala* (10-40 gms)	6	White spots on gills	*Thelohanellus catlae*
4.	Trichodiniasis	*C.mrigala* *C.catla* *L.rohita*	30	Pale cream color of gills	*Tripartiella bulbosa* *Trichodina* sp.

Trichodinid incidence has been high in all the carps. The presence of consistently high ammonia levels stressed the fishes, resulting in excessive mucus secretion. The population of the trichodinids in the fish gills increased because the mucus act as a substrate for the trichodinids.

Freshwater beels

Ulcerative dropsy

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

Symptoms: Accumulation of water in the body cavity with 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 associated with a large number of aquatic vegetation.

Treatment:

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

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

Trichodiniasis

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

Symptoms: Fishes with high infestations possess pale coloured gills with creamish coating. Surfacing of fish also common.

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

Treatment:- No viable treatment methods for open waters.

White gill spot

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

Symptoms: The gills of affected fishes 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.

Dactylogyrosis

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

Symptoms: Excessive secretion of mucus in the infected gills often with localized haemorrhage.

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

Treatment: Application of lime @ 100 kg/ha

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.

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.

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 prevalent. The potentially dangerous parasites and diseases existing in the Indian reserovirs are:

Ligulosis

Fish species affected: *C. catla*

Symptoms: Abnormal swelling of 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.

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.

Isoparorchiosis

Fish species affected: Murrels, catfishes and carps

Symptoms: Affected fishes become 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.

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

Stress in fish and its method of diagnosis

The term stress or stressor or stress factor is defined as the force or challenge in response to which there is a compensatory physiological change in fish. Thus, an environmental or biological stress is of significance if it requires a compensating response by a fish, population or ecosystem.

Incidence of fish disease is an important indicator of environmental stress. Fish disease is actually the outcome of the interaction among the fish, their pathogens and the environment. If the environment deteriorates stressed fish is unable to resist the pathogens that they normally can resist. Certain diseases are proving to be useful indicators that tolerances of adverse environmental conditions have been exceeded for example in some bacterial diseases and in trichodiniasi

Biological indicators of stress

In all the water areas mentioned i.e., the sewage fed bheries and beels the very common initial symptom of stress exhibited by fishes is excessive secretion of mucus from gills and body surface. In fact this physiological aspect of fishes can be fruitfully utilized for fish stress detection or detection of suboptimal water quality.

There are certain trichodinid parasites (*Trichodina* sp., *Tripartiella* sp.) ubiquitously present in fish gills especially of Indian major carps which can serve as good indicator of stress in fish. Excessive mucus secretion serve as substrate for these trichodinids which increase in number. A methodology has been developed where the presence of these trichodinids above 20 numbers in 0.05 ml of gill mucus is indicative of stress.

Use of the physiological response as indicators of stress

Several of the many changes that occur in response to stress can be used as measurable indices of the severity of stress on fish. These changes are a direct or indirect result of the physiological response to environmental changes and can be quantified and used as predictive indices.

The physiological changes that occur in response to abiotic stressor of sewage application is tabulated below (Das *et al.*, 1999) :

Table 4. Measurements of haematological parameters of *L.rohita* reared in the different experimental water bodies

Parameters	Normal	W2 (Sewage-fed)
Haemoglobin (gm/dl)	6.96 ± 0.2833	6.5± 0.3081
Haematocrit (%)	35.52 ± 1.2522	43.25 ± 1.198**
Leucocrit (%)	0.75 ± 0.0764	0.8 ± 0.0529
Clotting time (secs.)	34.7 ± 0.6991	51.3 ± 1.0254**
Plasma chloride (mfq/l)	92.5 ±1.5835	108.16 ± 0.7237**
Plasma glucose (mg/100 ml)	78.9 ± 2.3184	114 ± 1.7552**
Plasma cholesterol (mg/100 ml)	253.7 ± 2.5922	183.7 ± 1.7615**
Plasma protein (gm/dl)	2.03 ± 0.065	2.5 ± 0.0983**
Liver glycogen (/gm)	1.5 ± 0.1249	6.5 ± 0.3245
Plasma cortisol (ng/ml)	90.2 ± 1.7692	140 ± 1.6493**

The values Mean + SE indicates difference between the values of experimental fishes to normal fishes.
* indicates 5% level of significance, ** signifies 1% level of significance, n= 10 (no.of sample fishes)

The physiological changes that occur in response to the stress caused by capture, crowding and confinement are tabulated below (Sinha *et al.*, 1999).

Table 5. Influence of capture, crowding and confinement on the haematological parameters in *L.rohita.*

Parameters	Haemoglobin (gm/dl)	Haematocrit (%)	Leucocrit (%)	Clotting time (sec.)	Plasma glucose (mg/100 ml)	Plasma chloride (mEq)
1. Normal	7.5 ± 0.22869	32 ± 0.7096	0.66 ± 0.1288	41 ± 1.468	52.7 ±2.808	95 ± 2.394
2. Cast net capture and crowding in hundie for 1 hr.	7.6 ± 0.24	39 ± 0.8995**	0.6 ± 0.1194*	40 ± 0.7349*	67.0 ± 1.892	82 ± 1.229*
3. Cast net capture and confinement in happa for 12 hrs.	7.7 ± 0.075	44 ± 0.8124**	0.5 ± 0.0377*	38 ± 0.6033	64.0 ±0.6899	86 ± 1.470*

n=10, The significance of the difference of experimental fishes to those of normal fishes are shown as *5% level and **1% level

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 recent years, stocking of phytophagous carps *viz., C.idella, H.molitrix* and T.*mossambica* is 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

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Summer School on
Culture-based Fisheries for Inland Fisheries Development
CIFRI, Barrackpore 18 July to 17 August 2001

NEED FOR STOCK ASSESSMENT IN CULTURE-BASED FISHERIES MANAGEMENT

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INTRODUCTION

Among the inland aquatic resources, reservoirs, beels, oxbow lakes, derelict waters and canals can be put to culture-based fisheries. India has more than 19,000 small reservoirs with a total surface area of 1.48 million ha and about 180 medium and 56 large reservoirs of 0.52 and 1.14 million ha, respectively. Extensive areas exist under floodplain wetlands in the form of *mauns, chaurs, beels*, *jheels* in the eastern U.P., Bihar, West Bengal, Assam, Tripura, Manipur, Arunachal Pradesh and Meghalaya. They together form an area of more than 0.20 million ha. Small reservoirs and floodplain wetlands offer ample scope for developing culture-based fisheries.

The present production of fish in the country is estimated at 5.65 million t with almost equal share from marine and inland sectors. To bridge the gap between demand and supply culture-based fisheries has to play a vital role in coming years and needs immediate attention.

For development of fisheries, fishery managers need advice about the state of fish stocks. Stock assessment involves the use of statistical and mathematical tools to make quantitative predictions about the reactions of fish populations to alternative management choices. The main purpose of fisheries management is to ensure sustainable production from a system for the welfare of the fishermen and industries that use the production.

Mathematical models can be used to forecast the effects of increasing or decreasing effort and changes in fishing pattern. The fish stock assessment models can be broadly classified into two categories:

a) Analytical models
b) Holistic models

The analytical models are based on detailed description of the stocks and more demanding in terms of quantity and quality of input data. On the other hand, the holistic models require fewer population parameters. In this approach, a fish stock is considered as a homogeneous biomass and do not take into account, for example, the length or age structure of the stocks. Holistic models are mainly based on the concept of surplus production.

THE CONCEPT OF SURPLUS PRODUCTION

The changes in a population's biomass from one time to the next can be simply written as:

next biomass = last biomass + recruitment + growth – catch – natural mortality, (1)

if we ignore immigration and emigration. In the absence of fishing and by combining recruitment and growth into a single term called production, (1) can be rewritten as:

next biomass = last biomass + production – natural mortality (2)

If production is greater than natural mortality, the population will be growing, if it is less than natural mortality, the population will be declining. The term surplus production is generally used to represent the difference between production and natural mortality. Surplus production represents the amount, the population biomass will increase in the absence of fishing, or the amount of catch that can be taken while maintaining the biomass at a constant size.

The expected relationship between stock biomass and surplus production is depicted in Fig. 1. It is obvious that at low stock sizes there must be low surplus production because there are few individuals in the population to grow and reproduce, and at large population sizes the surplus production must again decline to zero because of slower growth, higher mortality rates, and limitations on recruitment.

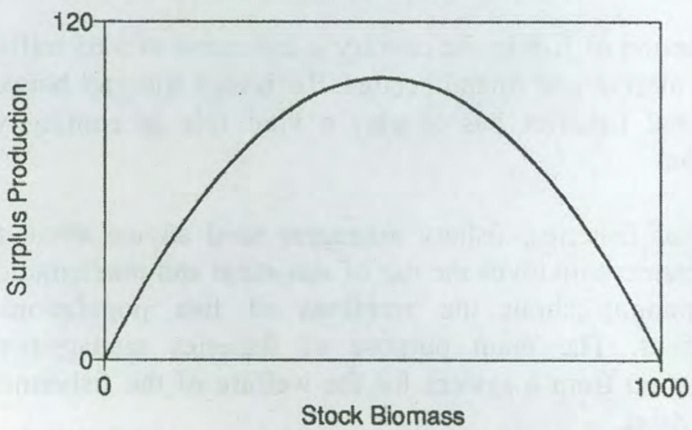

Fig. 1. Relationship between surplus production and biomass for the Schaefer model

The simplest model based on surplus production can be written as:

new biomass = old biomass + surplus production - catch, (3)

whch referred to as a biomass dynamic model or surplus production model.

Using biomass dynamic models in formulating fisheries management plans depends greatly on the quality of available data. When the fish biomass can be directly estimated, the graphical relationship between biomass and surplus production can be directly fit, whereas when the biomass cannot be directly measured and only an index of abundance is available, the estimation procedures become more complex and highly model dependent. As biomass is rarely measured directly, almost all applications of biomass dynamic models have used an index of abundance.

The first widely used biomass dynamic model was formulated by Schaefer based on earlier work by Graham. The objective behind the application of "surplus production models" is to determine the optimum level of effort, which produces the maximum yield and that can be sustained without affecting the long term productivity of the stock, i.e., the maximum sustainable yield (MSY).

THE SCHAEFER MODEL

Let,

f_i = *effort in the* i^{th} *year,* $i = 1,2,\ldots\ldots,n$

$\frac{y_i}{f_i}$ = *yield (catch by weight) per unit of effort in year i*

The simplest way of expressing yield per unit of effort, *y/f*, as a function of the effort, *f*, is the linear model

$$\frac{y_i}{f_i} = a + bf_i \qquad if \quad f_i \leq -\frac{a}{b} \tag{4}$$

This is known as the Schaefer model. The slope *b*, must be negative if the catch per unit of effort decreases for increasing effort (Fig. 2). The intercept *a*, is the *y/f* value obtained just after the first boat fishes on the stock for the first time. Therefore, the intercept must be positive. Then, *-a/b* is positive and *y/f* is zero for *f=-a/b*, because a negative value of catch per unit of effort *y/f* is absurd, the model applies only to *f* values lower than *-a/b*.

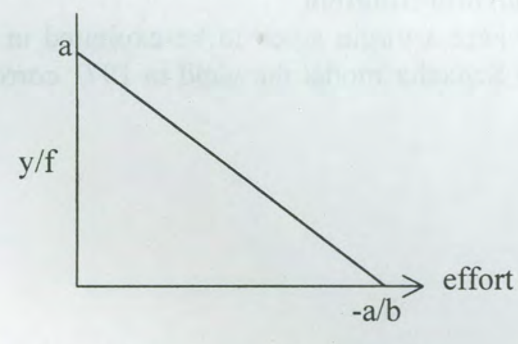

Fig. 2. Relationship between effort and catch per unit of effort

The catch per unit of effort can also be defined in terms of biomass (*B*) and catchability coefficient (*q*; a constant) as

$CPUE\ w(t) = qB_t$

Thus,

$$\frac{y_i}{f_i} = qB = a + bf_i$$

The biomass corresponding to $f=0$ is called the virgin stock biomass or the unexploited biomass, denoted by B_v. Thus, replacing y/f by qB_v

$$qB_v = a \qquad or \qquad B_v = \frac{a}{q}$$

The main objective of the stock assessment is to obtain an estimate of the maximum sustainable yield (MSY) and to determine at which level of effort MSY has been or will be recorded.

To obtain an estimate for MSY, the equation (4) can be written as

$$y_i = af_i + bf_i^2 \qquad if\ f_i < -\frac{a}{b} \tag{5}$$

or

$$y_i = 0 \qquad if\ f_i = -\frac{a}{b}$$

The eq. (5) is a parabola and after mathematical analysis we obtain the maximum value of the y_i, MSY level, at an effort level, is obtained.

$$f_{msy} = -\frac{a}{2} \tag{6}$$

and the corresponding yield

$$MSY = -\frac{a^2}{4b} \tag{7}$$

ASSUMPTIONS

The assumption of an equilibrium situation

Let us consider a situation where a virgin stock to be exploited in the year 1971 by 1000 boats. According to the Schaefer model the yield in 1971 corresponding to 1000 boats showed by x.(Fig. 3)

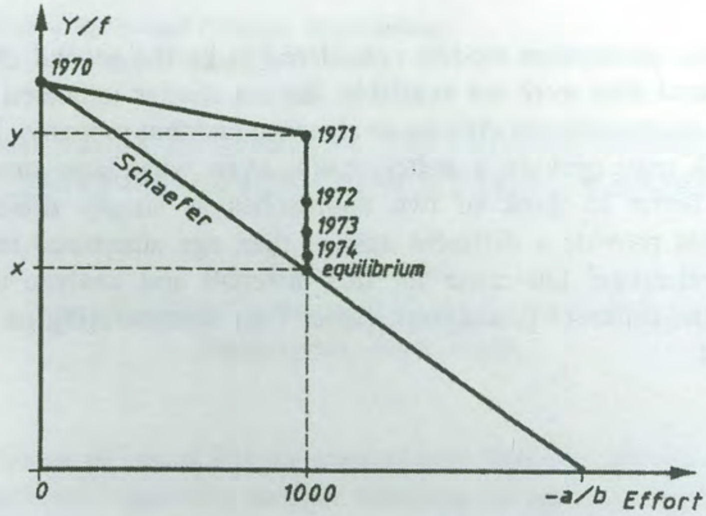

Fig. 3. Illustration of the concept of an equilibrium situation with transition period.

However, it turned out to be *y, i.e.* a larger value than predicted by the model. This is because when fishing started in 1971 the biomass was still the virgin stock biomass, B_v, and only after a certain period of exploitation the biomass declines.

Again in 1972 the biomass was reduced due to fishing in 1971 and the 1972 catch became smaller than that of 1971. Each year the resource is reduced, the reduction being smaller the larger the time has elapsed since the introduction of 1000 boats. Eventually, the system will stabilize at the *y/f* level *x*. This situation is known as equilibrium situation after a transition period. For the equilibrium situation the production of biomass per time unit, equals the removal by fishing, the yield per time unit, plus the amount of fish dying of natural causes.

Assumption on the catchability coefficient

Here it is assumed that fishing mortality is proportional to effort *i.e.*

$F = qf$

This assumption in itself is not controversial. The problem occurs when f is measured in, for example, the number of boat days per year over a series of years. In most cases the efficiency of boats has changed over a long period, often the boats have become larger and better equipped. Thus, 100 boat days in 1978 may create a larger fishing mortality than 100 boat days in 1968. This means that q becomes a function of time. It is very difficult to account for changes in q and usually it is assumed that q remains constant. Therefore, one should be cautious not to include too long a time series of data in the surplus production analysis.

Choice of models

In the past surplus production models considered to be the second choice, used only when age structured data were not available. Recent studies indicated that the choice between the two approaches may not be so clear cut and that in many circumstances the holistic approach may provide a better result, even when age structured data are available. It is better to think of two approaches as simply different. If surplus production models provide a different answer than age structured models, then one should try to understand the cause for this different and analyze the management implications of the different predictions, rather than concentrating on deciding which method is correct.

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QUANTITATIVE POPULATION MODELS FOR MANAGEMENT OF INLAND FISHERIES-CONCEPTUAL FRAMEWORK

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One of the objectives of inland fishery management is the maintenance of resource by assessing the stock and suggesting suitable measures for optimum exploitation. So, it is important to understand the dynamics of fish population in different inland waters for deriving maximum benefit in terms of sustainable fish production. A fishery resource is a self-renewable living natural resource in a dynamic habitat. Being a living resource, it always balances itself by adjustment of inherent biological characteristics like growth, recruitment and mortality. Before advising any measures, it is necessary to study the fish population dynamics and search for exploitation level, which in the long run gives the maximum yield from the fishery. For a given fishery resource there is, however, a largest average catch or yield that can be continuously taken from a stock under existing environmental conditions so that the stock remains uneffected. The ultimate objective of management programme of a given fishery resource therefore, is to assess the maximum sustainable yield.

OBJECTIVES OF THE FISH POPULATION DYNAMICS STUDY

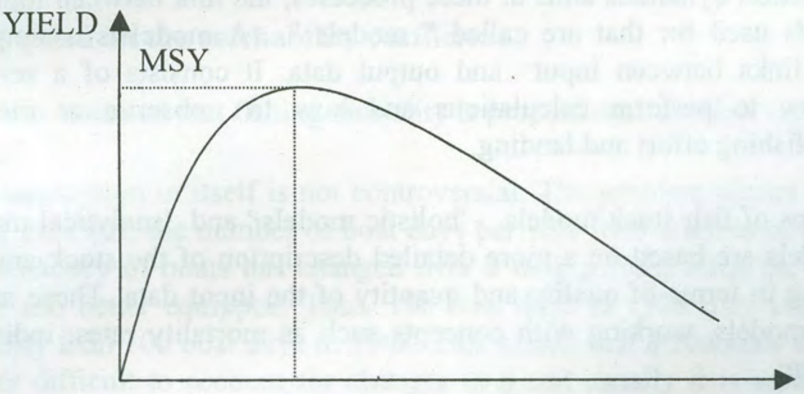

Fig 1. The basic objective of fish population dynamics

The data usually represent a time series of years. The models are based on assumption that the biomass of fish in a water body is proportional to the catch per unit effort. The surplus production models deal with entire stock, the entire fishing effort and total yield obtained from the stock. The main objective of the application of surplus production model is to determine optimum level of effort that produces maximum yield, which sustains without affecting the long term productivity of the stock. The production models can be applied when reasonable estimates are available on total yield (by species) and / or the CPUE by species and the related fishing effort over a number of years. The fishing effort must have undergone substantial changes over the period covered.

The holistic models are described here.

BASIC CONCEPTS OF SIMPLE LINEAR REGRESSION

If X and Y denote the two variables under study, the scatter diagram is obtained by plotting the pairs of values of X and Y along the X-axis and Y-axis in graph paper (Fig.2). The diagram thus potted gives an indication whether the variables are related, if so, the possible type of line or estimating equation can describe the relationship. If the scatter of points indicate that a line can better fit the data, then the relationship between the variables is said to be linear. If Y tends to increase as X increases, the relationship between the variables is said to be positive and linear. If Y decreases as X increases, the relationship between the variables is said to be negative and linear.

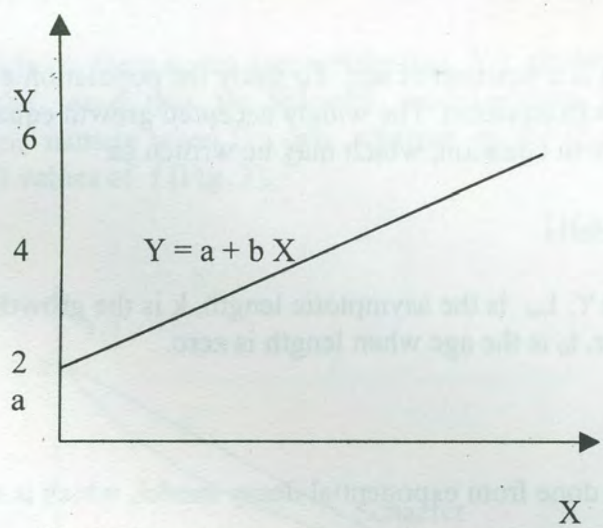

Fig 2: Linear regression of Y on X

If two variables are highly correlated, then the approach should be to study the nature of their relationship. Regression analysis achieves this by formulating statistical model, which can describe these relationships. Such a model enables prediction of the value of one variable, called dependent variable from the known values of the other variables. It differs from correlation in that regression estimates and the nature of relationship, the correlation coefficient estimates the degree of intensity of relationship. If scatter diagram indicates that the relationship is linear in nature, next step would be to develop a statistical model and proceed to estimate the underlying relationship. It is assumed that linear relationship of the form, Y = a + b X exists between the variables X and Y. Where, 'a' and 'b' are constants. 'a' is called as the intercept and 'b' is called as the slope. The intercept is the distance from the point (0,0) in the (X,Y) diagram to the point where the regression line intersects with the Y-axis. The slope b indicates the steepness of the line. The values of constants 'a' and 'b' are calculated through least square method from the observed data by the following formulae:

$$b = \frac{\Sigma xy - \frac{(\Sigma x \, \Sigma y)}{n}}{\Sigma x^2 - \frac{(\Sigma x)^2}{n}}$$

$$a = \bar{Y} - b \, . \, \bar{X}$$

Estimated values of these constants are substituted in the equation Y = a + b X to get the regression equation.

ANALYTICAL MODEL

Growth estimation

Basically the body size of fish is a function of age. To study the population dynamics of a fish we should know its growth equation. The widely accepted growth equation is known as von Bertalanffy growth equation, which may be written as

$$L(t) = L_{\infty} \, [1\text{-}\exp\{-k(t\text{-}t_0)\}]$$

where L(t) is the length at age 't', L_{∞} is the asymptotic length, k is the growth parameter/curvature parameter, t_0 is the age when length is zero.

Mortality estimation

The estimation of mortality is done from exponential decay model, which is written as

$$N(t) = N\,(Tr) * \exp\{-Z*(t\text{-}Tr)\}$$

where N(t) is the number of survivors at age t, N (Tr) is the number of recruits to the fishery, Tr is age at recruitment and Z is the instanteneous rate of total mortality.

HOLISTIC MODELS

The Schaefer and Fox models

The maximum sustainable yield (MSY) can be estimated from the following input data

f(i) = effort in year i, i = 1,2,.......n

Y/f = yield (catch in weight) per unit effort in year i.

The simplest way of expressing yield per unit of effort, Y/f, as a function of the effort f, in the linear model as suggested by Schaefer is:

$$Y(i) / f(i) = a + b\, f(i)$$

An alternative model was introduced by Fox. It gives a curved line, where Y/f are plotted on effort.

$$\log \{Y(i)/f(i)\} = c + d\, f(i)$$

which can also be expressed as

$$Y(i)/ f(i) = e^{c + d\, f(i)}$$

Both models conform to the assumption that Y/f declines as effort increases, but they differ in the sense that the Schaefer model implies one effort level for which Y/f equals zero, namely when f = -a/b whereas in the Fox model , Y/f is greater than zero for all values of f (Fig. 3).

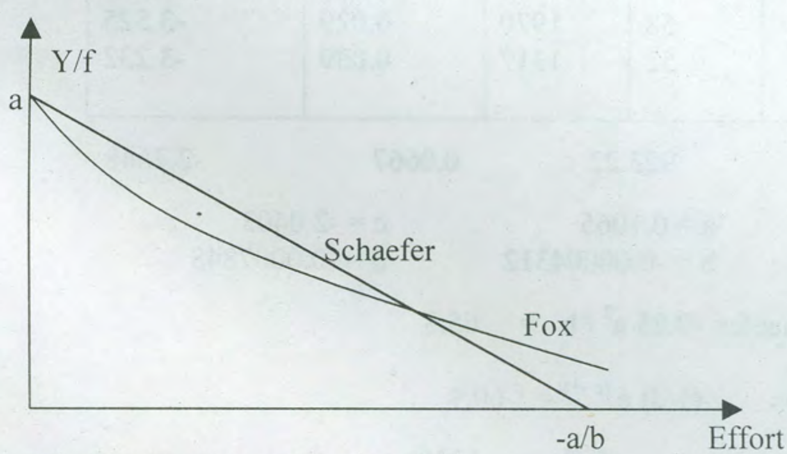

Fig 3. Schaefer and Fox model

The Schaefer's model can be written as

$$Y(i) = a\, f(i) + b\ f^2(i)$$

It has its maximum value of Y(i),the MSY level, at an effort level

$$f_{msy} = -\ 0.5\ a/b$$

and the corresponding yield

$$MSY = -\ 0.25\ a^2 / b$$

The Fox model can be written as

$$Y(i) = f(i)\, e^{c + d\, f(i)}$$

$$f_{msy} = -\ 1/d$$

$$MSY = -\ (1/d)\, e^{(c-1)}$$

Year	Yield Y(i)	Effort f(i) X	Schaefer Y(i)/f(i) Y	Fox log{Y(i)/f(i)} Y
1969	50	623	0.080	-2.523
1970	49	628	0.078	-2.551
1971	47.5	520	0.091	-2.393
1972	45	513	0.088	-2.434
1973	51	661	0.077	-2.562
1974	56	919	0.061	-2.798
1975	66	1158	0.057	-2.865
1976	58	1970	0.029	-3.525
1977	52	1317	0.039	-3.232
Mean		923.22	0.0667	-2.7648

$a = 0.1065$ $c = -2.0403$
$b = -0.00004312$ $d = -0.0007848$

MSY Schaefer $-0.25\ a^2 / b$ = 65.8

Fox $-(1/d)\, e^{(c-1)}$ = 60.9

f_{msy} Schaefer $-.5a/b$ = 1235

Fox $-\ 1/d$ = 1274

RELATIVE RESPONSE -MODEL OF ALAGARAJA

This model (Alagaraja, 1984) depends on successive catches to provide the maximum catch that the fishery can sustain. There are three assumptions for success of this model. These are (1) Stocks existing in a particular area are exploited by various types of gear that are not species specific. This implies that the effect of fishing on a mixture of stocks is proportional to the relative abundance of stocks in the mixture. (2) The fishing is increased over a time till the optimum level is achieved. (3) When the effort is increased the catches also increase till a maximum level is reached, but the rate of increase increases first and then decreases and finally reaches to nil. In progressive fisheries, where multispecies are exploited by multigears and when evaluation of effective effort poses problems particularly in tropical fisheries, this model is useful. The model in its simplified form is

$$C_{t+1} = a + b\,C_t$$

C_t is the catch of the t-th period, a and b are constants.

$$C_{max} = a/(1-b)$$

In progressive fishery the level of maximum catch can be predicted and suitable management measures may be suggested.

Example

The following data relate to the catch record from the Hooghly estuary for five years.

Year	Catch (t)
1	30578
2	37981
3	44628
4	48608
5	50713

Solution

C_t x	C_{t+1} y
30578	37981
37981	44628
44628	48608
48608	50713

$$C_{t+1} = 17038.8 + 0.703\,C_t$$

$$C_{max} = 17038.8/(1 - 0.703) = 17038.8/0.297 = 57369.7 \text{ t}$$

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ROLE OF PARTICIPATORY RURAL APPRAISAL AND CO-MANAGEMENT IN SUSTAINABLE CULTURE-BASED FISHERIES

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INTRODUCTION

India is bestowed with vast expanse of open water resources, which possess tremendous potentiality for enhancing fish production through rational management. The management norms should aim at sustainable production rather than yield maximization. In broad terms, sustainable development aims at improving and maintaining the production systems which sustain for a long time entire livelihoods of people. While sustainable development includes a broad spectrum of components *(viz.* better education, improved access to basic needs such as water, food and shelter, *etc.*), the viable ecosystems are seen as the basic life support systems. A basic tenet is the conservation of ecosystem functions and integration of culture operation in open water systems for sustainable fisheries development.

Successful ecosystem management for enhancing fish production usually depends upon the creation of partnership between the different users and beneficiaries. Thus, people are an integral part of culture-based fisheries management.

COMMON PROPERTY RESOURCE *VIS-À-VIS* CONFLICT

Wherever there is multiple use of natural resources, there is competition and conflict among different users. The prime aim of ecosystem-based management is to ensure multiple use by multiple users with minimum conflict or loss of values. Co-management is the sharing of authority and responsibility among government and stakeholders, a decentralized approach of decision making that involves user groups.

In reality, conflicts over natural resource use are rarely resolved completely, but specific agreements may be reached over the scale, location or zones and the time frames governing resource uses. The main aim in conflict resolution should be to attain balance among different uses, while ensuring that overall exploitation is kept within the capacity of the system. Thus, for sustainable development of common property resource, it is essential to involve local communities and other stakeholders. It is often easier and more appropriate to work with existing groups of stakeholders rather than trying to create new interest groups. A mechanism should be sought for briniging together representatives of the various categories of stakeholders for participatory rural appraisal (PRA) to identify constraints and differences, resolve conflicts, review progress, make collaborative management decisions, *etc.*

PARTICIPATORY RURAL APPRAISAL

Community-based organizations in fisheries sector whether in rural or urban contexts, have a key role in motivating members to participate in culture-based or other fishery efforts/ developmental activities in open water systems.

One of the most effective among the first generation methods of participation has been the highly influential *conscientisation* approach developed and promoted by the Brazilian educator Paulo Freire in the 1960s. This uses literacy programmes as a means of enabling poor people to discuss and analyze conditions in which they live and the underlying causes of those conditions. Freire's ideas have a considerable impact on small-scale development initiatives, especially in Latin America.

During the 1970s, the participating ideas began to develop and were put into practice in Asia, especially in farming systems. Academicians and social practitioners from developing countries became aware of these trends. Chambers continued to articulate the aims and methods of the basket of approaches often described as Participatory Rural Appraisal (PRA) since the late 1970s, or more recently as Participatory Learning and Action (PLA). PRA/PLA may be considered as second-generation (in case of PRA) and perhaps even third-generation (PLA, with greater emphasis on action) approaches to participation. The salient aspect of the approach is: ***the local communities and their members are the experts* and *the outsider is the ignorant one.*** The main aim here is not to change the system by overthrowing rich but to learn from the poor.

Some Sources of PRA

The past decade has witnessed more shifts from the rhetoric to practice in rural development. These shifts include the now familiar reversals from ***Top down*** to ***Bottom up,*** from centralized standardization to local diversity and from blueprint to learning process. Linked with these, there have also been small beginning of changes in modes of learning. In these changes, a part has been played by two closely related families of approaches and of methods, often referred as Rapid Rural Appraisal (RRA), which spread in the 1980s and its further evolution in PRA which begun to spread in the 1990s.

PRA has been called as *an approach and method of learning about rural life and its conditions.* It extends into analysis, planning and action. PRA as a term is also used to describe a variety of approaches. To cover these, a recent description of PRA is : *a family of approaches and methods to enable rural people to share, enhance and analyse their knowledge of life and conditions, to plan and to act.*

Five streams which stand out as sources and parallels to PRA are;

a) Activist Participatory Research
b) Agro-eco system analysis
c) Applied Anthropology
d) Field research in farming systems
e) Rapid Rural Appraisals

Principle of PRA

For both RRA and PRA, the good performance suggest that the practitioners and facilitators follow basic principles. Some are fully shared and some have been additionally emphasized in PRA.

THE RRA-PLA CONTINUUM

Name of process	**RRA**	↔	**PRA**
Mode	**Extractive-elicitive**	↔	**Sharing, empowering**
Outsiders' role	**Investigator**	↔	**Facilitator**
Information owned, analyzed and Used by	**Out siders**	↔	**Local people**
Methods used	**RRA**	↔	**PRA**

Principles shared by RRA and PRA

i) ***A reversal of learning*** : to learn from rural people, directly, at the site and face to face, gaining from local physical, technical and social knowledge.

ii) ***Learning rapidly and progressively*** : with conscious exploration, flexible use of methods, opportunism, improvisation, and iteration and cross checking.

iii) Offsetting biasses : by being relaxed and not rushing, listening not lecturing, probing instead of passing to the next topic, being unimposing instead of important and seeking out the poorer people and women and learning their concerns and priorities.

iv) Optimizing trade offs: relating to costs of learning to the useful truth of information with trade offs between quantity, relevance, accuracy and timeliness.

v) Triangulating : meaning using a range (sometimes three) methods, types of information, investigators and/or disciplines to cross-check.

vi) Seeking diversity : maximizing the diversity and richness of the information.

The Menu of Methods of RRA and PRA

In its early days, RRA seemed largely to be *organized common sense.* During the 1980s, creative ingenuity was applied and more methods were borrowed, adapted and invented with enhanced participatory mode.

- ***Secondary sources*** : such as files, reports, maps, aerialphotographs, articles and books.
- ***Do-it-yourself*** : asking to perform village tasks *viz*. aquatic weed control, predatory fish control, stocking, liming & manuring, sampling, harvesting etc.
- ***Key information*** : enquiring who are the experts and seeking them out.
- ***Semi-structural interviews*** : using participatory visual as well as traditional verbal method.
- ***Groups*** : group interviews and activities
- ***Sequences or chains of interviews*** : from group to group or from group to key informant, *etc.*
- ***They do it*** : villagers as investigators and researchers. They do transect, observe, and interview other villagers, analyse data and present results.
- ***Participatory mapping and modelling*** : people use ground, floor or paper to make social demographic, health, natural resources or farm maps or construct three dimensional model on their land.

- ***Participatory analysis of aerial photographs*** : to identify water resources, extent of weed infestation, soil type, land conditions, *etc.*

- ***Transect walks*** : systematically walking with informats through an area, observing, asking, listening, discussing, identifying different zones, local technologies, introduced technologies, seeking problems, solution and opportunities, mapping and diagramming resources and findings.

- ***Time lines*** : chronologies of events, listing major remembered events in a village with approximate dates.

- ***Trend analysis*** : people's accounts of the past of how things close to them have changed, ecological histories, changes in customs and practices, changes and trends in population migration, fuels used, education, health, credit, *etc.*

- ***Ethno biographies*** : local histories of crop, fish crop, animal, pest *etc.*

- ***Seasonal diagramming*** : by major seasonal or by month to show days & rains, crops, agricultural labour, fish farmer, fishermen, diet, food consumption, animal fodder, income, expenditure, debt, *etc.*

- ***Livelihood analysis*** : stability, crisis & coping, relative income, expenditure, credit and debt, *etc.*

- ***Participatory diagramming*** : of flows, causality, quantities, trends, ranking, system diagrams, bar diagrams, pie charts, Venn diagrammes, *etc.*

- ***Well being or wealth ranking*** : identifying clusters of households according to well being or wealth including those considered poorest of the poor.
- ***Analysis of difference*** : especially by gender, social group wealth/poverty, occupation and age.
- ***Scoring and ranking*** : especially using matrices through scoring.
- ***Estimates and quantification*** : often using local measures, judgements and materials such as seeds, pellets, fruits or stones, *etc* as counters.
- ***Key local indicators*** : poor people's criteria of well being.
- ***Key probes*** : questions which can lead direct to key issues such as – what is being talked about when together ?
- ***Stories, portraits and case studies*** : household history and profile, coping with crisis, and how a conflict was resolved.
- ***Team contracts and interactions*** : contracts drawn up by teams with agreed norms of behaviour; modes of interaction within teams, *etc*.
- ***Presentation and analysis*** : maps, models, diagram and findings presented by villagers or by outsiders are checked, corrected and discussed.
- ***Participatory planning, budgeting and monitoring*** : the villagers prepare their own plans, budgets and schedules and monitor progress.
- ***Brainstorming*** : by villagers alone, by villagers and outsiders together or by outsiders alone.

CO-MANAGEMENT FOR SUSTAINABLE DEVELOPMENT

In fisheries, the issue of linkages among stakeholders come up under the topics of community-based management, user participation in management and co-management. Co-management deserves special attention as it involves power sharing. It is one among the many different possible relationships between government agencies and local communities concerning resource management. Other relationships include consultative and advisory roles for local communities. Distinctly different from community-based management, the co-management strategy explicitly recognizes that government agencies must often be involved in community affairs for a variety of reasons including providing the resources not available in the community. However, it also recognizes the importance of community control over the exploitation and responsibility of many aspects of resource management.

Efforts have been made in recent years to incorporate the basic notions of sustainable development and ecosystem management approaches in national and regional development strategies and in policies dealing with biodiversity conservation and other utility functions. Success in achieving the same depends on understanding the characteristics of the ecosystem and the factors bringing change within it. However, there is a need for an interactive relationship between management actions and information requirements. The needs of management must be used to set the priorities for ecological and socio-cultural information besides the management actions should be adopted in accordance with information thus generated.

Why Co-management ?

Experimentation with fishery co-management is gaining ground on a global scale. The worldwide interaction on co-management arises in part because under other management processes effective linkages among public sector, private sector and communities have often failed to develop.

Co-management carries particular appeal in open water systems, especially for small scale fisheries, because of conditions under which such fisheries take place. Moreover, because of vastness and common property nature of openwater systems often need effective management. Small-scale fisheries may have local or regional importance disproportional to their size. In many areas fish are the basis for food security and nutrition for low-income group of people, who depend on the resource base for survival.

Evidently, finding effective ways to link stakeholders through resource management is critical for successful management success. The direct involvement of resource stakeholders in the planning and control of resource use, offers the potential for improving resource sustainablility. The idea behind co-management as a means to link stakeholders is that people vested in planning and decision making are more likely to pay attention to system level resource effects than those who are not.

Co-management: Functions and Elements

Co-management must perform the same functions like any other fishery management process. It develops goals for resource conservation and frame rules to allocate the resource between competing interests. It monitors fish population status and the impact on regulations. It is responsible for the enforcement of rules and the resolution of conflicts. Co-management has certain attributes that make it more effective in their functions because of different linkages it creates.

Co-management is based on several elements of group decision-making. These elements apply to the background conditions under which fishery management takes place. These are structure of decision-making, the transaction cost of decision-making and the human capital requirements of decision-making, all affecting the establishment of effective linkages.

Background condition

- ***Property rights :*** It connotes the set of entitlements to access and rules of use from people's expecations about their claims to the fishery. Property rights in some form are necessary for co-management because without them, there is no definition or assurance of legitimate participation or of the conditions that link user groups to each other and to the government. As long as rights are assigned and clearly specified, it can provide the appropriate background for co-management.

- ***Uncertainty :*** Uncertainty exists in all forms of fisheries as ecological systems vary, market expands and contracts, and government policies change. The type of uncertainty that exists in fishery shapes expectations and behaviour and also affects the links between users and government. There are ways that co-management can minimize the effects of uncertainty by broadening the sources of monitoring information, creating coordination between user groups, maintaining consistency in rules and incentives and clearly specifying procedures of decision making.

Co-management structure

- ***Boundaries :*** When co-management is applied within clearly defined boundaries, decision making is brought in, on line with existing ecological and political systems. Boundaries serve several functions; they define and limit the number of legitimate users, they define areas of control and they refer decision making to an ecosystem.

- ***Scale :*** Community-based management is nested within larger institutional jurisdictions, requiring that co-management process builds compatible incentives at different levels creating consistency in incentives. This is not easy because both *scaling up* small scale properties to large scale systems and *scaling down* large scale properties to local level can not be done proportionately. The number of boundaries or scales effects the cost and the effectiveness of establishing links.

- ***Representation :*** Linking stakeholders into management process is a critical element of co-management. The organizational task is to maximize representation so that decision reflects the full array of interests and so stakeholders are vested in the process.

- ***Participation :*** Various levels of user participation are possible within a co-management process ranging from information exchange to consultation to active self-governance. The type of participation is determined by the human capital embedded in stakeholders and in the resource available for co-ordinance.

- ***Transaction costs :*** Any organizational structure embodies cost. The structure of co-management importantly influences its cost because it determines as to how the stakeholders are organized, information is generated and used, decisions are made and monitoring and enforcement take place. These costs are called transaction costs and while costs are an inevitable part of resource management, their magnitude and therefore, their influence can be influenced by management.

- ***Human Capital*** : Transferring responsibility for various management functions from the government to stakeholders under co-management also transfers the requirements for human capital stakeholders. Thus the development and effective use of human capital among stakeholders are essential for co-management. Co-management requires certain skills and knowledge to be available as human capital stock, so that the flow of services can be sustained. The stock of human capital is contained in education, knowledge, and skills of stakeholders. Flow of human capital services are required for the tasks of coordination, negotiation, scientific review, design, monitoring and enforcement.

CONCLUSION

Building consensus among stakeholders on the objectives and levels of use of natural resources is essential for sustainable development. Government may decrease their involvement in the extensive day-to-day responsibility of resource management at community levels through collaborative management agreements like co-management with participatory approach.

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SOCIO-ECONOMIC ASPECTS OF CULTURE-BASED FISHERIES

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INTRODUCTION

Fishery development aims at productivity enhancements for exploited stocks and increasing the exploitation of under-utilized fish stocks. It is possible by expanding effective effort through allocation of additional labour and capital, technological upgradation, training, etc. Fishery management, requires better economic efficiency including reduction in fishing costs and in turn fishing effort, which would ultimately lead to reduction of fishers and fishing assets. Management involving the retirement of a group of fishers is unjustified and often non-enforceable in the absence of alternative employment opportunities, within or outside fishery. It would raise equity implications by imposing a cost on a low-income group in order to generate an economic surplus for the society as a whole. The steps for management and institutionalization of fisheries, particularly of reservoirs and floodplains, involve conversion of capture fisheries operations in to culture-based fisheries. These interventions benefit some groups of fishers, but they can also harm few others, due to denial of fishing rights. Their implementation, though, justified on aggregate economic grounds, but may be constrained by variety of social considerations. Since, fisheries development and management involve and affect primarily the fishers, it is necessary to consider their social aspects including employment, mobility, subsistence orientation of production and income distribution with regard to culture based fisheries, in the light of their relative socio-economic conditions.

EMPLOYMENT AND MAXIMUM SOCIAL YIELD

The most important social aspect is employment generation through culture based fisheries, which can be computed through maximum social yield (MscY).

The introduction of social aspects in bio-economic model is a new concept of fisheries management *viz*., The MscY (Panayotou, 1982). It is basically a modified maximum economic yield (MEY) and is equal to sum of wages and surplus profits. Introduction of social considerations may either limit the speed or extent of introduction of management measures or justify more development than is justified on purely economic grounds.

In case of considerable unemployment, fishing wages do not reflect the true opportunity cost of labour. Fishers have no alternative fishing, because of widespread unemployment, therefore their opportunity cost is close to zero which implies that the society makes little or no sacrifice in keeping them in the fishery. Evidently, while calculating the cost per unit of effort, c, and the total cost (TC) curve, the opportunity cost or wages to be paid to fishers should not be included. These are not a cost to the society. In case of widespread unemployment the total fishing costs, TC', are lower than the total costs under full employment (TC), because the former do not include the cost of labour while the latter does (Figure 1). It results in maximum social yield (MScY) at a level of effort E_{MScY} considerably higher than E_{MEY} (the level of effort under full employment). Although, the surplus profits at E_{MScY} are lower than at E_{MEY} (*i.e.,* dg < ab), but the social yield being the sum of surplus profits and wages is higher at E_{MScY} than at E_{MEY} by the amount of df, *i.e.,*

$$dg + gh > ab + bc \quad \text{or} \quad dg + gh - (ab+bc) = df$$

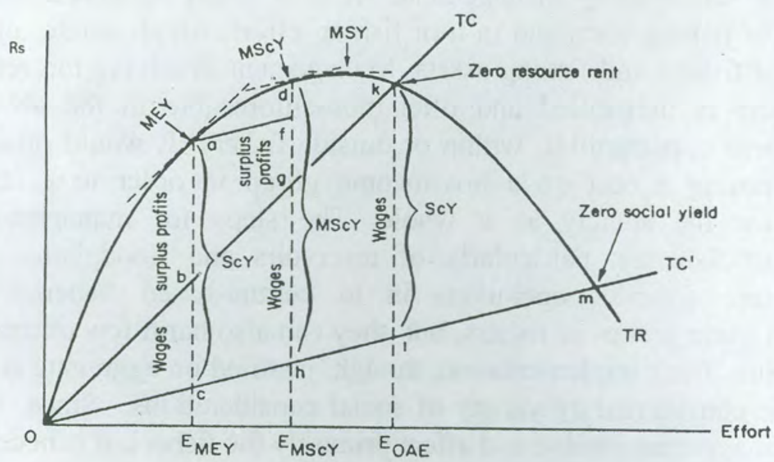

Figure 1. Maximum social yield in absence of alternative employment opportunities

Thus, df is the net social benefit from allowing effort to expand from E_{MEY} to E_{MScY}. However, expansion of effort beyond E_{MScY} should not be allowed, since the social surplus (profits and wages) is reduced. At open-access equilibrium level of effort, E_{OAE}, the social surplus kl consisting entirely of TR, the losses are so high that all wages are absorbed and only capital and running costs are covered by the gross proceeds and hence the social surplus is effectively zero. Thus, the maximum social surplus (M_{ScY}) obtained at E_{MScY} level of effort is equal to dh and consists of dg amount of surplus profits and gh amount of wages.

Considering no alternative uses for fishing assets (crafts and gears), the TC will shift even lower than TC' justifying an even higher level of fishing effort but yet lower than the open access equilibrium level of effort, E_{OAE}.

The secondary employment generated through the multiplier effect (fish processing and marketing, non-fishing investment of fishing profits) is reduced if we operate right to E_{MScY} and such reductions may offset any gains in fishing employment. Hence, the maximum social yield cannot be to the right of MScY, even with high priority on the employment objective.

MOBILITY

According to a bio-economic model, fishers will stay in the fishery as long as they earn an income at least as high as the opportunity cost of their labour and capital. As the fishery becomes over-crowded and profits for most fishers disappear, who are not able to earn adequately from the fishery and change both occupation and location if necessary, *i.e.*, a perfect mobility of labour and capital.

Lack of occupational and geographical mobility may result from long isolation, low formal education, advanced age, preference for a particular way of life, cultural taboos, caste restrictions, inability to liquidate one's assets, indebtedness or just lack of knowledge and exposure to opportunities. The consequence of immobility is that fishers may continue fishing even if they earn far less than their opportunity costs.

In fact, many of the socio-economic problems of culture-based or small-scale fisheries arise from the asymmetry between entry and exit. To enter the fishery, especially in a good fishing year, is relatively easy. To leave, especially in a bad fishing year, is quite difficult, as a fisherman might not be able to afford to spend time looking for a job or moving when his income is down to subsistence level or he can hardly expect to find a buyer for his fishing assets during a bad fishing year.

SUBSISTENCE ORIENTATION OF PRODUCTION

The bio-economic model assumes that the objective of every fisherman is profit maximization. It would not change the results of the model, if profit by income is replaced. However, it has often been argued that artisanal or traditional fishers are engaged in fishing not for profit but for subsistence; but, even subsistence is made possible either by consuming one's produce or by selling it for cash income. Moreover, considering the higher prices received by fish, it is no more a subsistence commodity (*i.e.*, it is not a staple). A fisherman's subsistence depends almost entirely on his income whether as a boat-owner or labourer. Thus, the earnings of income are clearly the intermediate objective of those engaged in fishing.

The objective of some fishers may be to earn a certain level of income rather than maximize that income. In such cases they behave differently from the rational fishers of bio-economic model who chase every fish, which has a price tag higher than the cost of catching it. Fishers who go after a target level of income reduce their efforts when fishing is very profitable (because present stage of fishing is sufficient to meet their target) and increase their effort when fishing is poor, a behaviour with grave implications for both fisheries development and management. This subsistence oriented production is an important socio-economic problem with most of the fishers, which needs to be attended.

INCOME DISTRIBUTION

The purpose of fisheries management from the economic point of view is to maximize the aggregate social benefit without consideration of who gets what. However, given the dualism that exists in many fisheries, such as poor and well off fishers including boat owners and labourers on the one hand, and the objectives of many governments to reduce income disparities on the other. It is often appropriate to attach a bigger weight to the benefits accruing to poor fishers than to well off fishers. This would mean that social benefits would increase as a result of a change in the sharing system which increases the share of the actual fishers, or as a result of a fisheries regulation which allocates more culture based fisheries resources to poor fishers. But, these social aspects are rarely addressed with zeal to help poor. In most of the cases, the higher share of benefits of fisheries enhancements is being taken away by management group with elite personnel.

SOCIO-ECONOMIC IMPACT IN CULTURE-BASED FISHERIES

Impact on fishing rights, fishing practices and conservation measures

The impact of recently concluded World Bank assisted Fish and Shrimp Culture Project (Anon, 2000) on fishing rights, fishing practices and conservation measures is depicted in Table 1.The results varied across different states and water bodies. Regarding change in fishing rights, majority of the water bodies had no change, except in case of reservoirs in Uttar Pradesh, where 80% of the fishers were denied fishing rights after implementation of the project. The fishing practices remained the same for most of the water bodies adopted, except reservoirs in Andhra, where pen culture was used for raising the stocking material and major fish harvesting was once a year. In rest of water bodies, stocking rate has improved without adopting pen culture. The conservation measures were well accepted in Uttar Pradesh and Bihar, while insignificant in Andhra, particularly due to one time fish harvesting.

Table 1. Fishers' response towards change in fishing rights, fishing practices and conservation measures

(in % of water bodies)

Water body / state	Change in fishing rights				Change in Fishing Practices		Conservation measures					
	Yes	No	Denied fishing		Yes	No	Closed season		Mesh size regulation		Fish size Regulation	
			Yes	No			Yes	No	Yes	No	Yes	No
Reservoir												
Orissa	43	57	43	57		100		100	43	57	3	97
Andhra	19	81	5	95	93	7	10	90	2	98	2	98
Uttar Pradesh	60	40	80	20	20	80	100		100		100	
Oxbow lake												
Uttar Pradesh		100		100		100	80	20	80	20	80	20
Bihar		100		100		100	100		100		57	43

Impact on fish marketing practices

In majority of the water bodies fish marketing had changed, as co-operatives were included in marketing channel, after implementation of the said project (Table 2). More than one fish disposal practices were observed in most of the water bodies, except reservoirs in Uttar Pradesh and oxbow lakes in Bihar. But, majority of fish catch was passed through co-operatives. The commission charged by co-operatives was less than half, except in reservoirs of Orissa and lakes of Bihar.

Table 2. Fishers' Response towards change in marketing practices

(in % of water bodies)

Water body / state	Change in marketing Practice		Existing marketing practices			Commission charged by society
	Yes	No	Individual	Co-operative	Both	
Reservoir						
Orissa	30	70	40	43	17	60
Andhra	37	63	5	100	5	37
Uttar Pradesh	100			100		45
Oxbow lake						
Uttar Pradesh	40	60	60	100	40	40
Bihar	14	86		100		56

Impact on functioning of fisher co-operatives

Most of the fishers in adopted water bodies were members of operating co-operatives (Table 3). There was significant improvement among them after the Project was implemented.

Table 3. Fishers' response towards functioning of co-operatives

(in % of water bodies)

Water body / state	Member of Co-operative		Is co-operative Useful		Change in functioning of co-operative				Is there any change in subscription	
					Yes	No	If yes			
	Yes	No	Yes	No			Positive	Negative	Yes	No
Reservoir										
Orissa	96	4	85	14	75	17	70	5		98
Andhra	79	21	99	1	95	5	93	2		
Uttar Pradesh	100		100		100		100			100
Oxbow lake										
Uttar Pradesh	100		100		89	11	89		49	51
Bihar	86	14	89	11	89	11	89			100

Impact on literacy level of the fishers

The average age of the fishers was around 40 years (Table 4), and in the range of 18 to 63 years. The literacy percentages for the fishers alongwith their family members varied between 23 % in oxbow lakes of Uttar Pradesh to 67% in the reservoirs of the same state. The majority of literate fishers were studied only upto primary level. The better awareness, returns and standard of living led to increase in literacy rate of the fishers of adopted water bodies both in terms of number and higher education.

Table 4. The average age and literacy level of fishers

(In %)

Water body / state	Average age of fishers (year)	Qualification				
		Illiterate	Primary	Middle	Matric-ulation	Intermediate and above
Reservoir						
Orissa	37	42	40	9	8	1
Andhra	40	50	25	6	12	7
Uttar Pradesh	40	33	44	11	6	6
Oxbow lake						
Uttar Pradesh	37	77	6	8	6	3
Bihar	40	40	37	17		9

Impact on fishers' assets

The change in fishers domestic and productive assets due to project is represented in Table 5. The domestic assets have increased for most of fishers, particularly in reservoirs of Uttar Pradesh and Andhra and oxbow lakes in Bihar. In case of fishers of reservoirs in Orissa and oxbow lakes in Uttar Pradesh this percentage was comparatively low. The fishery requisite structure revealed that large number of fishers have purchased crafts after implementation of project in all the States except Andhra Pradesh where these belong to Cooperative and not individual fisher. Among the gears gill net was the most prevalent. The dragnets were common only in Orissa. The cast nets were operating mainly in oxbow lakes of both the States. Evidently, a marked change in assets was observed in most of water bodies.

Impact on fish production and income

Most of the fishers of adopted waters had reported an increase both in fish catch and fish business income (Table 6 and 7). Over 90% of fishers from all the states under study had higher average annual catch and income, except the fishers of reservoirs in Orissa. Increased stocking rate was the most important factor for increase in fish catch, followed by rise in fishing effort and they enhanced productivity. The other responsible factors for increasing income in Uttar Pradesh and Bihar were better catch composition, fish prices and marketing practices.

Table 5 Fishers' response towards change in assets

(In %)

Water body / state	Change in domestic assets		Change in fishing assets							
	Yes	No	Craft acquired		Gill net acquired		Drag net acquired		Cast net acquired	
			Before	After	Before	After	Before	After	Before	After
Reservoir										
Orissa	47	53	16	69	24	94	50	44		8
Andhra	70	30								
Uttar Pradesh	83	17	36	20	46	32	22			
Oxbow lake										
Uttar Pradesh	46	54	25	18	48	21	17		39	12
Bihar	94	6	89	12	100	25			49	21

Table 6 Fishers' response about increase in fish catch and its probable reasons

(In %)

Water body / state	Increase in catch		If yes, due to					
	Yes	No	Increased Productivity	Increased Fishing Effort	Increased Stocking Rate	Conser-vation practice	Manage-ment practices	Other
Reservoir								
Orissa	48	23	1	4	48	2	1	1
Andhra	91	7	53	3	84	1	22	2
Uttar Pradesh	100		89	94	100	28	17	28
Oxbow lake								
Uttar Pradesh	97	3	74	69	86	3	3	3
Bihar	94		74		86	3	23	23

Table 7 Fishers' response about change in income and probable reasons for the change

(In %)

Water body / state	Change in income		If yes, due to			
	Yes	No	Increased Catch	Catch Composition	Better Prices	Marketing
Reservoir						
Orissa	32	20	31	1	0	1
Andhra	89	8	89	1	2	2
Uttar Pradesh	100		100	83	67	33
Oxbow lake						
Uttar Pradesh	94	6	80	57	34	3
Bihar	91		86	43	60	9

Impact on the employment status

In the present investigation on culture-based fisheries the rise in catch and income were accompanied with better employment prospects for most of the water bodies. The major reasons attributed for it were adoption of rational stocking, and increase in effort both in labour and capital.

Table 8 Fishers response about additional employment

(In %)

Water body / state	Additional employment generation								
	Yes	No	No Res-ponse	If yes, due to					
				Rearing upto fingerling	Watch and wards	Increase in effort			Marketing
						Man-power	Craft	Gear	
Reservoir									
Andhra	91	4	5						
Uttar Pradesh	100			60	60	60	60	40	20
Oxbow lake									
Uttar Pradesh	20	80		20	60	60	60	60	20
Bihar	46	40	14			42	28	35	56

Macro-level appraisal of socio-economic aspects of culture based fisheries

The micro-level socio-economic impact analysis of the Project revealed improvement in fisheries management practices, fish catch, income and employment and overall increase in living standard of concerned fishers engaged in culture-based fisheries. But at macro level the parameters of employment, mobility, subsistence orientation of production and income distribution found to be relatively less encouraging. The employment prospects had increased at the project sites and surrounding water bodies (spillover effect), yet, the restrictions on free entry led to an employment level much below E_{MscY}. Many fishers already fishing in the adopted waters were denied fishing rights in changed management and property regimes. In the wake of scarce alternate employment opportunities, there was no perfect mobility of these fishers either in fishery or other enterprises. As such they were the sufferers due to project implementation. Regarding, subsistence orientation of production, the project had mixed success in rationalising the fisher towards maximising their profits from culture based fisheries. In the state of Andhra Pradesh, where the fishers were more adaptive and innovative to materialise maximum benefits of the project, the impact was better. The fishers got the much-needed impetus for fisheries enhancements. In this context, the project could make only a headway, in Uttar Pradesh and Bihar, but the results from Orissa were not encouraging. The other important socio-economic parameter is income distribution or equity related aspects, whose success can be measured in terms of extent of equi-distribution of derived benefits among all concerned including the labourers and management personnel. In this context, fishers, response revealed mixed outcome, with low success in the states of Uttar Pradesh and Bihar to significant impact in Andhra.

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INSTITUTIONAL ARRANGEMENTS IN CULTURE BASED FISHERIES MANAGEMENT

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INTRODUCTION

The functioning and outcome of any production system depend largely on its production efficiency, administrative acumen and the environment in which it operates. The institutional arrangements of any production system form an integral part of its environment, in which both production and administration process take place. Therefore, these arrangements play important role in overall performance of a production system. The role of institutional arrangements becomes more pronounced for the production systems utilising natural and man-made resources having multiple uses. Fisheries in general and culture-based fisheries in particular are typical examples of such production systems. The present paper concentrates more on the subjective aspects of the institutional arrangements and management regulations including their classification, criteria for selection, property and management regimes under which these are implemented and finally brief description of arrangements in different culture-based fisheries resources.

CLASSIFICATION OF INSTITUTIONAL ARRANGEMENTS

The institutional arrangements in culture-based fisheries may be classified into two broad categories: (a) arrangements which aim at increasing the efficiency of fishery and of overall economy through removing impediments to growth, and, (b) arrangements for redistributing income and reducing socio-economic disparities. The first category of arrangements may lead to provision of infrastructure, improvement of fish utilization and marketing efficiency, research and extension, promotion of fishers' organisations, better fishers' remunerations, *etc*. The second category may address the equity issues through appropriate allocation of fisheries resources to different individual fishers and fisher groups, belonging to various socio-economic strata. There may also be a third category of institutional arrangements, which addresses both the objectives of efficiency and equity. It may be in the form of subsidies of any sort as well as credit.

CRITERIA FOR SELECTION OF APPROPRIATE INSTITUTIONAL ARRANGEMENTS

A number of criteria may be used to select an appropriate form of institutional arrangements. The criteria as well as selection of institutional arrangement depend primarily on the government policy, objectives and prevailing circumstances. The major criteria are briefly discussed below:

1. Any institutional arrangement should provide help to the fishers and does not hurt them either in short or long run. It presumes anticipation of both the short and long-term effects of intervention. For example, in an open-access fishery characterized by immobility and subsidies on input costs or fish prices may lead to short run profitability, but, excessive entry and reduction in fishing incomes of existing fishers below their pre-intervention levels in long-run, may harm them.

2. There should be focus on factors of production which cannot be provided or procured by the fishers themselves either because of economies of scale in their provision or because of their sheer cost relative to the fishers' income. For example, institutional arrangements for providing infrastructural support such as landing facilities, roads and market outlets in the public domain. At the other extreme, there are factors of production such as ice and nets, which are private goods and should be the responsibility of the fisher himself. In between, there are the capital inputs such as boat and engine, whose costs are high, compared to the fishers' incomes and for this purpose institutional arrangements for credit facilities may be justified.

3. Between number of alternatives, the highest cost-effective arrangement should be selected, which attains a given objective or set of objectives with the least cost. For example, fishers are not adopting a new profitable technology, either due to lack of knowledge of its existence or lack of confidence in its profitability. The alternative institutional arrangements may either be transferring the technology free of cost to the fishers or providing them with the appropriate information and extension about technology to convince them for adoption. The latter is most cost-effective, therefore, may be preferred. Similarly, if fish prices are relatively low because of inappropriate fish utilization or high marketing margins, the most cost-effective arrangement is not a price support scheme or a fish price subsidy but improvement of fish utilization and of marketing efficiency.

All the aforementioned criteria for selecting forms of institutional arrangements indicate that the state should not intervene directly with fishing operations through input subsidies or fish price support. Given the constraints (scattered fisheries, limited resource, open access, multiple uses, conflicts with large-scale fisheries and limited mobility), any such interventions are likely to: (a) prove very costly and difficult to withdraw; (b) hurt, rather than help, the fishers in the long-run; (c) lead to further distortions of the markets and depletion of the resources; and (d) leave the society with a larger problem in the future and with fewer resources and lesser ability to deal with it. Instead, institutional arrangements should concentrate on creating an appropriate environment in which small fishers can operate in more even competition with each other and with large fishers.

Direction of institutional arrangements under resource constraint

The institutional arrangements would, sooner or later, be proved futile, if equity issued are not properly addressed. It is true, as far as the socio-economic conditions of the fishers and long-term interests of society are concerned. Under the binding of resource constraint, the arrangements with low emphasis on equity would result only in a temporary increase in fishing incomes at the expense of permanent reduction in the fishery's net economic surplus (already zero before the intervention). The effect on employment is ambiguous, since any gains in primary employment arising from the expansion of effort should be balanced against reductions of secondary employment arising from the reduction in catch. Improvement of the environment in which culture-based fisheries operate is effective even if the resource constraint is binding, provided effort is controlled. However, creation of supplementary or alternative employment in presence of resource limitations and surplus labour in fishing communities, is a *sine qua non* for upgrading culture-based fisheries and uplifting depressed fishing communities. Therefore, under open-access and resource constraint binding, the institutional arrangements should only be directed to create alternative employment to yield long-term benefits.

Direction of institutional arrangements under no resource constraint

In the absence of resource constraint binding, institutional arrangements for fishery development in the form of either subsidies or infrastructure may result in long-term increases in catch and employment, but not in income or in economic surplus whose changes are either temporary or ambiguous. Institutional arrangements for fisheries development have persistent positive effects only when fishing effort is regulated, particularly if, the resource constraint is not binding. Although, under these conditions both direct intervention through subsidies and indirect intervention through creation of conducive environment (infrastructure, improved catch utilization, more efficient marketing, etc.) would work, yet, the criteria of "cost-effectiveness", "easy withdrawal" and "minimum distortion" favour the latter.

MANAGEMENT REGULATIONS

The choice of management alternatives depends largely on the specific features and circumstances of the fishery concerned and the objectives of the management authority. Yet, this choice should be based on a set of criteria as detailed below:

Acceptance by the fishers: For a management regulation to have a fair chance of success at economically justifiable enforcement cost and a politically acceptable degree of coercion, it must have the support of the majority of the fishers. This is especially important in small-scale or culture-based fisheries, where enforcement is complicated by the dispersion and fluidity of fishing units.

Gradual implementation: Fishers are not likely to agree to any regulation, which would deprive them from access to the fishery or in any way threaten their absolute or relative position in the fishery, unless appreciably superior alternatives are proposed. Even then, social factors and other causes of mobility may prompt them to oppose regulations, which they see as a threat to their traditional way of life and source of livelihood. Hence, a second criterion for the selection of an appropriate management regulation is that it should be amenable to gradual implementation. For example, the auctioning of fishing rights is likely to exclude, right from the start, many small-scale fishers with no alternative employment.

Flexibility: An appropriate management regulation should be sufficiently flexible to allow for adjustment to changes in economic and biological conditions. Flexibility in multi-species fisheries is particularly important in circumstances of limited knowledge of species interactions and of the reactions of stock composition to changes in effort. In recent years, economic conditions (e.g. fish prices and fish technology) have been changing rapidly. Management regulations should be so flexible that they can be subjected to necessary modifications in accordance to the changed environment.

Encouragement of efficiency and innovation: The regulation should encourage the fishery to operate at the minimum average cost, and provide incentives (or, at least, leave scope) for improvements in efficiency through both tactical changes in the pattern of fishing and innovative changes in fishing technology. This is of utmost importance, since higher efficiency means larger spread between the value of the catch and fishing costs and hence higher income for the fishers and/or economic surplus for the society.

Full cognizance of regulation and enforcement costs: The management regulation should take full account of the research, enforcement and monitoring costs involved and political factors constraining its effective implementation. For example, mesh size regulation or taxes on effort may be very costly to implement in scattered multi-gear fishing units.

Due attention to employment and distributional implications: Lastly, an appropriate management regulation would take full cognizance of the employment and distributional implications. It should also weigh them against the other objectives of fisheries management (improvement in fishing incomes, maximization of economic surplus, reduction of gear conflicts, etc.).

On the basis of these criteria and the constraints under which culture-based fisheries operate we can attempt an evaluation of the potential applicability and effectiveness of the management alternatives: gear selectivity, gear restrictions, seasonal and area closures, catch quotas, fishing effort controls, economic controls (taxes, license fees and price controls), and territorial rights (property rights over the stock or an area, leasehold arrangements, franchises and rights of use).

THE REGIMES FOR IMPLEMENTATION OF INSTITUTIONAL ARRANGEMENTS

The environment in which the institutional arrangements are implemented *i.e.* the property and management regimes is equally important.

Property regime

The property regime is generally concerned with the ownership or right to use a natural or man-made water resource. It has serious implications on fish production process and institutional arrangements, as these are conducted and implemented under different social environments or property regimes. The method, tenure and other terms and conditions for conducting fisheries operations or transfer of fishing rights are at the discretion of its owner. Therefore, property regimes have direct bearing on outcome of any production process and performance of institutional arrangements. The property regime may be classified as open access, common property regime, private property regime, and multiple user ownership.

Open access: Under open access property regime, everyone has equal right of fishing in any water body. No one has the right to exclude anyone from fishing in any natural or man-made water resource. So, a conservative dictum "everybody's property is nobody's property" (Gordon, 1954) holds true, as open access is likely to be abused, misused, and overexploited. As a result, number of active fishers is large in this regime due to free entry. This type of fishing regime may be irrational, as there is no control on fishing effort, fishing method and area of fishing. The implementation of institutional arrangements and management regulations becomes difficult under this property regime.

Common property regime: Sometimes common property regime is confused with open access. The only difference between them is that the former is open access for the local or limited users only, not for everyone from anywhere. Comparatively, these waters can be managed better than open access, as there is some restriction on entry and control on fishing effort, method of fishing and fishing area. In this case implementation of institutional arrangements and management regulations is comparatively easier, due to monitoring and control on fisheries operations.

Private property regime: The private property is said to be exclusive because the owner can exclude others from appropriating the property and /or benefits from it. In this sense, private property is commonly conceived as individual property. The property owned by other entities like a co-operative or company is also a private property, as these entities can legally exclude others from using it. Due to exclusiveness in use, this type of waters can be managed efficiently, subject to fisheries management acumen of the owner or manager. This regime provides a congenial atmosphere for implementation of institutional arrangements and management regulations and the chances of their success are better.

Multiple user ownership: In case of many natural or man-made waters, the resource is used for multiple uses. For example, reservoirs created for irrigation and hydro-power generation, are also used for fisheries, domestic water use and so on. Therefore, fisheries management operations should be in relation to other activities, which restricts their degree of freedom.

Management regime

The property regimes are concerned with the right to use any resource, but the problem "how to use the resource" falls under the purview of management. After having the fisheries management rights, the fish production process is managed by different management systems or regimes, under given property regime. The management regime may be i) individual, ii) group (s) of individuals, or iii) organisation. These are responsible for implementation of fish production practices, institutional arrangements and management regulations. Therefore, outcome and efficiency of fish production process, and performance of institutional arrangements and success of management regulations largely depend upon the management regime.

INSTITUTIONAL ARRANGEMENTS IN DIFFERENT CULTURE-BASED FISHERIES WATERS

The culture-based fisheries waters in our country are primarily in the form of reservoirs and floodplain wetlands including sewage fed fisheries.

Reservoirs

The reservoirs are mainly the irrigation or hydroelectric power projects, so, mostly belong to irrigation department or under the control of boards or authorities (IIM, 1985). The latest information on size-wise distribution of these reservoirs for different states is complied by Sugunan (1995). Most of them were adopted for fisheries after construction, therefore the fisheries component was missing during its planning. It resulted in absence of pre-impoundment survey and operations. Submerged trees, rocks, *etc.*, influence the fishing activities in the reservoirs. Their removal in the later stages would enhance the management costs. For better fisheries management of the reservoirs on scientific lines, its management board should have representation from fisheries. Since, these water bodies, if managed properly for fisheries operations, prove to be very effective in enhancing the incomes of rural masses in addition to providing them sufficient employment as in the case of Gobindsagar and Pong Dam reservoirs in Himachal Pradesh (Katiha, 1994). Therefore, it should be mandatory to include fisheries expert during planning phase of any river valley project.

The fisheries in these water bodies are generally considered as a secondary activity, primary being the irrigation and hydropower generation. The department of fisheries or other fisheries agencies generally obtain the fishery management rights from the owner of the reservoir, with or without paying some royalty/nominal amount. In some states, the fisheries department transfers the fishing rights to some other government/co-operative/private agency and receive the royalty with / without rendering any fisheries development services.

One of the most important institutional arrangements for exploitation of fisheries in reservoirs is leasing system. It depends on trends of fish production, income and expenditure of the department, socio-economic conditions of the fishers, government policy towards co-operatives and above all status of states' fisheries resources and the area of the reservoir. In the states of Uttar Pradesh and Rajasthan, generally the reservoirs are leased according to their area as follows: i) below 100 ha for one year, ii) 100-500 ha for 3 years iii) 500-1000 ha for 5 years and iv) above 1000 ha for 10 years. For large and medium reservoirs, the major management emphasis is on stocking policy; while for the small reservoirs, other fisheries enhancements under culture-based management also play significant role. In some states reservoirs entrusted to state agencies for monitoring of fish stock through stocking and check on harvesting consistently maintains good production level, while in the reservoirs under control of private contractors, the results are not very encouraging. If the fisheries management vests with co-operatives, the results are moderate, but requiring a proper supervision at stocking and fish harvesting stages. The reservoir leasing systems and fishing rights in different states are summarized in Table 1.

Flood plain lakes

The floodplain lakes are distributed mainly in the states of Assam, Bihar and West Bengal. A study conducted by CIFRI, Barrackpore described the distribution and classification of floodplains in India (Sugunan and Bhattacharjya, 2000). In Bihar, most of the lakes are public property barring few with private ownership (Sinha and Jha, 1997). The government has classified them under two categories (i) lakes with *makhana* and lotus; and ii) lakes without *makhana* and lotus. The fishing right in both the types of lakes vests with department of fisheries, although, for the former category of lakes, it is with revenue department. These are auctioned annually by the fisheries department to local fisher co-operatives. The auction amount varies according to area and pattern of fish catch. Many of the lakes could not be adopted for fisheries due to unsettled disputes and claims of co-operatives. The recent upsurge in number of fake co-operatives tends to increase rivalry and litigation. There is an urgent need for effective enforcement of fisheries and co-operative legislation towards proper fisheries development and conservation of these water bodies.

Table 1. Leasing systems and fishing rights in reservoirs of different states

State	Leasing systems and fishing rights
Andhra Pradesh	Open auction for private contractors, departmental fishing, licensed fishing, free licensing system, share system
Bihar	Departmental fishing with 50% share of fishers, open auction with 10% concessions for co-operatives and first year stocking by fisheries department
Gujarat	Leased to Gujarat Fisheries Development Corporation or Gujarat Fisheries Central Co-operative Association Ltd. with varying rate of royalty and target quota, These bodies either conduct yearly auction to contractors or give fixed rates to licensee fishers. The fisheries department monitors the fish harvesting to control over-exploitation.
Haryana	Open auction for fishing only in the month of May
Himachal Pradesh	Annually leased to local co-operatives on the basis 15% royalty to department. The fisheries management is done by fisheries department including stocking practices and monitoring of fish harvesting and conservation activities.
Karnataka	Fishing rights including exploitation, stocking and leasing out vested with department of fisheries. In some cases the department pay royalty in the form of fixed percentage of returns to the owners, i.e. department of irrigation, village Panchayat, etc. Fisheries department also issues licenses to fishers with fee based on types and quantity of nets used.
Madhya Pradesh	Leased to Madhya Pradesh State Fisheries Development Corporation on some fixed royalty per tonne. Corporation collects royalty from fishers at prefixed rates for their catch. Annual contract for reservoir fishing is based on tenders with highest royalty for different varieties.
Maharashtra	Leasing priority is for Co-operatives @ maximum water spread X fixed rate per ha for three years; otherwise the department stocks the reservoir and issues monthly licenses to fishers of different co-operatives; department issues permits to members of co-operatives and charge royalty on some fixed rate
Orissa	Department of fisheries and Orissa Fish Seed Development Corporation stock the reservoirs. These are leased out to co-operative at some fixed rate per sq mile; in absence of co-operatives open auction is followed.
Rajasthan	Open auction for one year with 12.5% concession to co-operatives, long term lease with 5% annual increase in lease amount
Tamil Nadu	Departmental fishing, lease to State Fisheries Co-operation / Fisher Co-operatives based on royalty or share basis, licensing to fishers on monthly/yearly basis.
Uttar Pradesh	Open auction for i) one year with size <100 ha ii) three years for 100–500 ha iii) five years for 500-1000 ha and iv) ten years for >1000 ha.
West Bengal	On lease to West Bengal State Fisheries Development Corporation (WBSFDC) on nominal rent. WBSFDC engages the fishers of co-operatives on 50% share basis.

Modified from Anonymous (1994)

The short term leasing policy of fisheries department also effects the fisheries of these lakes (Jha, 1997). Due to short period of lease the lessees are not interested in investing money for fisheries development in the lakes. On the contrary, they try to catch out the entire fish, irrespective of size and species, resulting in further depletion of fish stock. It would amount to converting these most fragile ecosystems into biological deserts.

Sewage-fed fisheries

A resume of case studies on institutional arrangements in sewage-fed fisheries in the estuarine wetlands (*bheries*) in West Bengal is depicted in Table 2.

Table. 2 Institutional arrangements in *bheries* of West Bengal

Particulars	Zone				
	Low Saline		Medium Saline		
	With sewage		With sewage		Without sewage
Location of bheri	Machhi Bhanga	Machhi Bhanga	Minakhan		Harishpur
Area (ha)	10.66	17.33	46.00	13.33	37.33
Ownership of land	Private Multiple	Private Multiple	Private Multiple	Private Multiple	Private Multiple
Leased out through	Open auction	Open auction	Open auction	Open auction	Open auction
Month of auction	November-December	November-December	November-December	November-December	November-December
Lessee	Individual*	Individual	Individual	Individual	Individual
Lease amount (Rs/ha.)	56250	60000	39000	39000	82500
Lease period (years)	1	1	3	3	2
Disposal of fish to	Wholesaler	Wholesaler	Wholesaler	Wholesaler	Wholesaler
Name of Market	Kharibari	Kharibari	Maalanch	Maalanch	Basirhat/ Ketia
Approximate price (Rs per kg) for *P. monodon*	350	450	500	500	400
Number of employees					
a) Permanent	4	6	15	9	20
b) Casual	6	4	10	6	5
Wage rate (Rs per month)					
a) Permanent	1400	1600	1600+ 1% of sale proceeds	1600+1% of sale proceeds	2000
b) Casual	Royalty	Royalty	Rs 25 per day	Rs 25 per day	Royalty
i) For harvesting	1400	1500			
ii) For watch and wards					

* Leased in the name of one person but has 5 partners

The land of all the *bheries* is privately owned with multiple ownership. The number of landowners varied from 150 to 300. The *bheries* were leased out to individuals through open auction. The auction was generally done in November or December. In few cases, although, the water body was leased out to individual, but the lease amount was shared by more than one person. The lease amount varied between Rs 8,250 to 60,000 per ha. The amount of lease varied according to the productivity, and type of production system followed *i.e.* paddy cum fish culture and fish culture or tank fisheries. The *bheries* with sewage impact were more productive so, have higher lease amount. Regarding, the production system the *bheries* with tank fisheries alone were leased out at a higher amount as compared to those having paddy cum fish culture. The lease period varied from 1 to 3 years.

For all the *bheries,* the fish catch was disposed to wholesalers, who either procured it at assembly centre or at landing center. The fish catch was preferably disposed to nearby fish market. Generally, for the whole lease period, the lessee was bound to sell their catch to a particular wholesaler. It was due to the fact that wholesaler had paid a sizeable amount as advance, which was utilised by lessee to pay a part of lease amount. The per kg price received by the lessee for *P. monodon* ranged between Rs 350 to Rs 500.

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LIVELIHOOD ISSUES OF THE FISHERS IN THE CULTURE- BASED FISHERIES

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INTRODUCTION

Every individual is associated with some sort of economic activities for sustaining the life of his/her family. These economic preoccupations are the source of livelihood, which determine survival and well being of the individual and family. Households generally do not depend on only one source of livelihood; they tend to diversify their sources constituting the diversified baskets. These baskets of different livelihood sources constitute livelihood system. This livelihood comprises as array of the economic activities undertaken by the households for their sustenance, which include labour, agriculture, fishing, small business activity and other subsidiary occupations. Out of these activities or enterprises, one or two constitute the major sources with others becoming supporting livelihood sources.

The fishers are primarily dependent upon fisheries for their livelihood. The degree of dependence varies from sole dependence to the fisheries as the subsidiary income. Their involvement in fisheries also varies from catching fish to preparation of boat and net making and selling fish. Therefore, the discussion on the livelihood encompasses all these functions undertaken by the fishers and all the people dependent upon fisheries in one way or other. The commercial operators in fisheries, who have taken up fisheries as alternative source of income, are not put in the center of attention in this discussion. Though, there is no water tight compartment between these two, the central focus of the present discussion is on the people who are exclusively dependent upon fisheries for their livelihood.

WHY LIVELIHOOD SECURITY IS IMPORTANT?

The issues of food security have come into prominence in recent times. A large section of people under the clutches of poverty struggle hard to search food on a sustainable basis. Therefore, food security encompasses the ability of the household to arrange food not just for the day but for the coming times on a sustainable basis. The food security is directly related with the security of the enterprises or the resources on which people are dependent as source of livelihood. The livelihood security is a logical corollary of food security.

The renewed thought in resource management suggests livelihood security as an end to resource management. The productivity and sustainability are the means of achieving it. This perspective is also applicable to fisheries resources and looks at fisheries beyond the issues of productivity and sustainability. Fisheries as an occupation is not only for producing fish at higher quantity and quality but is also a means of food security to a large number of people collectively termed as fishers.

THE LIVELIHOOD ISSUES

The livelihood issues are much wider than the issues affecting the resources and their management. The fisheries involve the complex interaction of the natural processes and the social and individual actions. The various factors or issues related with fisheries ultimately affect the livelihood of fishers. These emerge out of both natural and socio-economic processes and are intricately interrelated forming complex web of cause and effect. Therefore, it is difficult to single out the issues as isolated ones; they need to be seen in the context of their interdependence. However, these issues may be discussed at three levels viz., (i) resources (ii) management and (iii) consumption.

Resources Level

Natural and ecological issues

The inland capture and culture-based fisheries mainly consist of the rivers, reservoirs, and wetlands. The capture fisheries resources are quite large in its expanse and are not under the control of any single individual or entity. This facilitates the high rate of the degradation. Habitat destruction, reduction of the fish stock, pollution, lack of attention towards the conservation of fish biodiversity and the ecology *etc.* are reducing their natural capacity of production. This has led to the decline in the productivity of capture fisheries all over the world. The shrinking base of the fisheries production is the major cause for livelihood insecurity.

The unplanned development and lack of national priorities towards the water resources may be the main reasons attributed for this natural degradation. Fisheries come in the lower order of the priority as compared to the drinking water, industrial uses and irrigation. The water use planning is favoured towards the other use of water. The incentives and regulatory measures don't deal comprehensively with the degradation and pollution. The ecological systems are quite interdependent and the development in the catchment areas affect the fish resource productivity.

Control and rent

As discussed earlier, the productivity of the resource is the output of interaction between the environmental function and the human action. The combination of these two is different for the different resources. The captive resources like agriculture and aquaculture are fundamentally based on the human efforts, but in the capture and the culture-based fisheries, the contribution of the environmental functions is much higher. The role of control is more important in these resources. The person who controls the resources through ownership, lease, contract or forceful occupation tends to harvest higher level of return. The fishers have to pay rent or share of the produce against the control function of the water bodies. The state owned water bodies are also under the lease arrangement taking a substantial share of the fish business income in the form of rents. These control functions are mostly in the hands of the private or commercial entities; the rents collected are usually not used for fisheries development. Therefore, ethical issues emerge as who should control the environment. The debate over the environment and the development favours the fishers as the primary stakeholders of these water bodies. A mechanism needs to be developed for the participation of the fishers in controlling water bodies and utilisation of the rents in favour of fisheries development.

Issue of access

The capture and culture based fisheries resources are vast in their magnitude. Their size varies from a few hectares to thousands and spread over many states of the country. It makes the control of these resources difficult. The vastness of the resources also gives rise to multiplicity of uses like fisheries, irrigation and agriculture in the marginal areas. The complexity and multiplicity of the users lead to the state of multi stakeholders in these resources. This gives rise to the complex system of rights and control over the resources. Worldwide trend suggests a gradual drift in these rights towards more exclusivity. The traditional regimes were predominantly non-exclusive rights for the fishing and other uses *i.e.* the resources were mostly under the open access system. The fishers enjoyed unrestricted access to fishing as compared to the restricted access in the present regimes. In many cases, the access has been governed by the rents, sharing of output with the right holders. This has been reducing the fishers' share to a substantial degree. The terms of the distribution are inclined more towards the right holders like lessee, controller, owner, *etc.* The fisher is at loss both in terms of the direct sharing of the output as well the potential loss due to denial of access.

Management Level

Commercialization of fisheries operations

In recent times the structure of fisheries organizations has been changed drastically. There is an increase in the demand for the fisheries products at national as well as international market. This can be attributed to change in taste and preference, increase in population, increased standard of living, expansion of the marketing network, *etc.* The gap between the demand and supply is ever increasing, putting pressure on the supply side of the fisheries. This phenomenon is leading towards more marketization and commercialization of fisheries operations. The private bodies, market functionaries and commercial operators are playing important role in commercial fisheries. Certain operations like carrying, auctioning, selling, retailing, *etc.* are the new functions taken up by the fishers but the more remunerative functions like lease, financing, processing, trading, transportations etc. are still in the hands of commercial operators. These operators are substituting the traditional fisheries organizations and institutions. The issues of the food and livelihood insecurity for fishers are the outcome of this transition.

The privatization policy and participation of market forces

The policies in fisheries and related areas influence the fisheries management systems. Significantly the leasing policy decisions play important role in capture and culture based fisheries. These are more inclined towards the private individuals or commercial operators. The large water bodies need higher investment in terms of the lease-rent and transaction cost in acquiring and maintaining of the lease. The individual fishers are not financially sound to invest. The other alternatives would have been the group mobilization of the fishers in co-operatives or organizations. The co-operatives and cooperative governance are in bad shape all over the country. The co-operatives have been managed like the government organizations and lack the flexibility and dynamism essential to compete with the commercial operators. The policy makers see the cooperatives as failed institutions. There are many traditional fishers organizations, which are not recognized by the public institutions and policy makers. The traditional organizations don't function efficiently. Therefore, the policy makers overlook the existing fisheries organization during decision-making process. The policies are directed towards increasing production to reduce the gap between the demand and supply. This consideration favours the economically efficient organizations. It leads to the exclusion of the fishers from remunerative and vital function of fisheries. This accounts for the entry of new functionaries, which are more organized and economically efficient in their *modus operandi*. The fishers are left with the functions having low remunerations.

Other policy issues

There are other policies of macro economic dimensions linked with the livelihood of fishers. The policies related to credit, infrastructure, development, market regulation, price information network, subsidy and other promotional provisions applied to all other sectors also affect the fisheries. These policies are primarily not directed against fisheries but indirectly affect the livelihood of fishers. The credit policy, for example, determines the access of the credit to fishers. The security and guarantee needed for the credit is difficult for the resource-poor fishers to arrange. The credit is the most important governmental assistance for the fishers to take up new operations and increase their income and standard of living.

Similarly, setting up of a fish processing unit is directly related with the policy support of the government. The processing units increase the demand and price of the fishery products, which will help in strengthening the livelihood support system of the fishers. The participation of fishers in the value addition of fish products helps in the diversification of the livelihood. It may also increase the income of the fishers substantially.

The market regulation measures are required to curb malpractices and restrictive practices of the market. These measures improve the market efficiency resulting in low prices to the consumer and high prices to the fishers. The fish market at the lower end of the marketing channel is highly disorganized and the perishability of the produce makes these markets highly inefficient. Therefore, the increase in the efficiency in marketing system will directly improve the income of the fishers. Various studies suggest the producer's share to the consumer rupees are of the order of 40-50 percent. The issues of the market regulation and marketing efficiency are related with the returns to the fisher. The increase in the returns will have favourable impact on the standard of living of the fishers.

Policy towards fisheries organizations, community mobilization

There are two conflicting approaches for fisheries development. The first is a purely economic activity and the other aims at the welfare of fishers' community. The former approach endeavours to improve the economic efficiency of the fishery production. It targets at an increase in production, reduction of cost and supports of the economically efficient operators. But the later approach is broad based, attempting to integrate the social dimensions in fisheries development. The development of the fishers organization like cooperatives, self help groups, community mobilization for the larger participation of the fishers in the production, capacity building of these groups and supporting the civil society for achieving the social objectives are the intricate part of strategy for livelihood enhancement of the fishers. However, in recent times the social dimensions are put in the corner in favour of the economically efficient fisheries. The fishers are basically resource poor and illiterate. It puts them in the unfavourable platform to compete with the commercial operators. With the perspective of economically efficient fisheries in the forefront, the fishers are increasingly marginalized in the fisheries operations. Their participation is confined to the traditional areas attributed with high drudgery and less remuneration. Their capacity to participate in the more remunerative and new operations are extremely low.

Economics of fisheries operations and sustainability

The issues of livelihoods in capture and culture-based fisheries are complicated primarily because of the nature of the resources itself. The vastness of the resources makes it difficult to control. The large number of fishers depending upon these resources work as individual operator. But the resource needs collective actions for protection and the conservation of the resource to maintain productivity on a sustained basis. The collective measures like protection of breeding ground, mesh size regulation, complying to the closed reason in the fish breeding period *etc.* are important for sustainability. There is ever increasing number of people depending upon it. This is leading towards rapid deterioration of the productive capacity of the resources. The individual fishers are facing diminishing return to the effort. In order to compensate, they increase their effort like improving the catch efficiency of net, use of small meshed size, putting more hours of effort *etc.* These practices have enormous social cost attached to it. It is dangerous to the sustainability. There is an inherent contradiction between private gain and social cost; and short and long term advantages in the capture fisheries. Moreover, the diminishing return to the effort is not economically sustainable as unit cost overrun the return. Therefore, these contradictions leading towards unsustainability are major threat to the livelihood security of the fishers.

CONSUMPTION LEVEL

These are basically the micro level issues close to the consumption end of the fisheries. These include the issues relating to the fisheries institutions, social security, bargaining ability, level of diversification *etc.* The institutional network of the fishers is determinant of their collective effort and bargaining. The collective ownership of crafts and gear is important to earn their livelihood. The interrelationship among the group members determines the relative share in the output. Similarly the interrelationship between the controller or the owner is reflected in their bargaining for share in catch. In many cases, the sharing arrangements are institutionalized. The collective operations contribute towards the social security measures *i.e.*, the group support of each other in the ailment or minor accidents. Certain amount of social security measures are undertaken by the government in the form of the public distribution, consumption, loans, *etc.* There is a complex relationship between social security and bargaining ability. Similarly, the diversity in livelihood also contributes to increase the bargaining ability of the fishers. The higher bargaining ability increases the share from the catch as well as other operations. The issues at this level are mostly related with the social environment of the fisheries.

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AN EFFECTIVE PROCESS APPROACH AND RESPONSIBLE FISHERY MANAGEMENT IN THE CONTEXT OF INLAND FISHERIES

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In recent years, many inland open water fisheries that rely completely on the natural fish production process are exploited above or close to their sustainable maximum. As a result, production levels of these kind of systems have reached a plateau. Increased pressure on fishery resources, environmental degradation of aquatic habitats and poor fisheries management have contributed to such a situation. Conventional fisheries management measures such as regulation of minimum mesh sizes, closed areas and closed seasons are commonly used to remedy this situation. However, these measures are often difficult to enforce and do not always increase or maintain production levels especially when the fishing pressure is high or the environment is already degraded. In such situation, other techniques such as enhancements are used to intensify fish production. Enhancements of inland aquatic resources for fish production though offer a useful tool for improving food security and poverty alleviation, their possible environmental impacts (especially with respect to introduction of exotic species) are to be addressed. These emerging situations call for attitudinal change to development (from project to process approach) and management (from production at all costs to sustainable production) in the context of inland fisheries.

FISHERIES MANAGEMENT AND DEVELOPMENT

In simple terms, fisheries management can be defined as 'the pursuit of certain objectives through the direct or indirect control of effective fishing effort or some of its components in a natural fishery'. Although scientific fisheries management is a concept of western origin, the general idea that fisheries have to be managed in some way or other is found all over the world, even in the so-called 'unregulated fisheries'. Development, on the other hand, implies some form of improvement in a fishery. Often the terms management and development are confused. Management is often called upon only after a fishery becomes over-exploited, whereas development should be applied when a fishery is under- exploited (i.e., catches are less than what the resource can possibly yield). The two concepts are closely interrelated. Management is required long before a fishery is biologically over-exploited, while development is needed when a resource has been over exploited. The general view is that management without some elements of development is impossible and *vice versa*. Both management and development aim at achieving optimum or best possible use of a fishery resource. How this optimum (biological, economic or social) is defined depends on the specific objectives set for a particular fishery or economic sector of a particular country.

THE PROCESS APPROACH TO DEVELOPMENT OF INLAND FISHERIES

Limitations of the project approach

In the conventional project approach to development (e.g., stocking of floodplain lakes in Bangladesh under the Third Fisheries Project during 1991-96 with WB and ADB loans) funding for all the developmental works (including technical assistance inputs) is mostly met from external sources. Thus, the project approach (as opposed to the process) to fisheries development often means that when a project ends, so do the activities. This can have adverse effects on the fishing communities since availability of fish is severely curtailed. More importantly, there is a danger of loss of confidence of the target groups in the development programmes. In addition, most fishery development projects have so far been managed almost entirely by the government, with only limited involvement of fishing communities except in harvesting. The development programmes, therefore, suffers from the constraints inherent in public interventions such as excessive bureaucracy, inadequate social mobilization, creation of a dependency syndrome and unwillingness of the fishers to participate in the development process. Also conflicts between agriculture and fisheries (for control of sluice gates/water level) and between established fishing groups and others (who want to fish) are likely to arise following public interventions.

An effective process approach to development

In order to overcome some of the limitations of the project approach the approaches to development of inland fisheries (including enhancements) should be led by the principles of participation and empowerment of all stakeholders; integration of technical, institutional, social and economic analysis; learning from development experience and adaptation of policies and procedures; and accountability.

A process approach should be followed to carry out any intervention in inland fisheries so as to ensure higher success rates. A wide range of options and alternatives to the proposed developmental activities should be considered. The expected benefits and costs of different options and the uncertainties surrounding these should be evaluated. Learning should be made an objective of the intervention. Options available should be evaluated for their potential to yield information as also for technical, social, economic and environmental benefits. Outcomes of all interventions should be continuously monitored and feed back obtained from such monitoring provided for the improvement of policies and procedures in future developmental activities.

Stakeholders should be involved at all stages of the developmental programme to ensure overall sustainability of the programme. The management and funding responsibilities for continued fish production after the initial development should be transferred in a phased manner to the fishing communities, with NGO support. This may, in some cases, involve the transfer of ownership of the revenue fisheries (e.g. *Meen mahals* of Assam) to these communities.

Suitable arrangements should be made to ensure the equitable distribution of benefits to fishers, particularly poor landless groups. These may include benefit-related gear licensing, lease cancellation, extension and training services, credit facilities to targeted groups and continued support from NGOs.

There is a need to continue the research and monitoring programmes to identify any negative environmental impacts which may appear over period of time. Future developmental programmes of similar nature may have to be modified in the light of these findings.

RESPONSIBLE FISHERY MANAGEMENT OF INLAND FISHERIES

Changing attitudes to fishery management

Until the last decade, the main objective of fishery management was to increase fish production from a water body by all possible means. However, attitudes to the management of natural resources are changing all over the world in recent years. These changes arise mainly from concerns about the state of the aquatic resources being under increasing pressure to satisfy a range of demands. Most important among these is the need for food, especially in tropical countries. In addition, the sustainability of the living aquatic resources is threatened by pollution and environmental degradation. The United Nations Conference on the Environment and Development in 1992 has provided moral framework and guidelines for the sustainable use of natural resources. At the same time the Convention on Biodiversity was formulated and has now been accepted or acceded by 176 countries, which provides the only international legal framework for conservation and sustainable use of living resources.

The code of conduct for responsible fisheries

Most of the world's natural fisheries are over-exploited or are about to become so. This trend is more evident in inland waters, especially rivers, which are almost without exception excessively fished. In addition, there is high degree of alternative use of water for industry, agriculture, power generation, urban water supply and transport which influences the structure of the environment. To counteract these threats fishery mangers have to represent the interests of their sector in decision making mechanisms at all levels. At the same time, fisheries have to rationalize its own operations. One of the first steps in this process has been the adoption by countries of the Code of Conduct for Responsible Fisheries, as adopted by the Food and Agricultural Organization's (FAO) Committee of Fisheries in 1995. The code furnishes voluntary guidelines on the organization of fisheries at national level and sets out principles and international standards of behaviour for responsible practices in order to ensure effective conservation, management and development of living aquatic resources, with due respect for the ecosystem and bio-diversity. It recognizes the nutritional economic, social, environmental and cultural importance of fisheries and the interests of all those concerned with the this sector. It also takes into account the biological characteristics of the resources and their environment as well as the interests of consumers and other users. In short, the Code is one of the most important international instruments devised for wholesale management of the living aquatic resources of the world.

The Code is presented under twelve articles and two annexes, of which article seven deals with fisheries management. To support implementation of the code at national and local levels, the FAO has developed nine technical guidelines in collaboration with member-countries and various organizations, one of which is on inland fisheries. Together, the Code is a guiding principle on how sustainable fisheries can be achieved at national, regional and international levels in all aspects of fisheries and aquaculture. It, together with the Convention of Biological Diversity, also emphasizes the need for countries to regulate their aquatic environment for conservation of aquatic biodiversity and for sustainable fisheries.

Changing perspectives in fisheries management

The objectives of fishery management are changing rapidly in many parts of the world as policy makers adjust to the new vision of the resources. The trends appear to be influencing the direction of management at present.

i) Emergence of new conservation oriented objectives for natural resources management.

ii) Changing patterns of use within the fishery. Increasing pressure on fisheries to satisfy the urban needs of fish supply and recreation tend to inflate the pressure on the resources as well as displace the food fishery with drastic effects on food supplies and employment.

iii) The emergence of new philosophies for participatory management. In fisheries where the basin approach is crucial for protecting migratory or transboundary stocks, there is suppression of national authority. On the other hand, there is a trend for devolution of national powers to local authorities within the country. This trend is further decentralized in case of co-management systems where the fisher communities share responsibility for management.

Responsible management of inland fisheries - some compatible practices/ strategies

While the principles and objectives of responsible fishery management have been universally accepted, there is difference of opinion as to which of the practices/ strategies can be included under responsible fishery management. Nevertheless, the following practices appear to be compatible with the concept.

Habitat protection, physical rehabilitation of the ecosystem and other improvements such as establishment of fish sanctuaries, desiltation of feeder canals (in case of open *beels*) and installation of fish passage facilities (across impoundments).

Enhancements (of species, stocks, environment, etc.) are likely to result in a significant increase in production from inland waters with associated benefits. However, aquatic resources available for enhancements are finite and the number of fish species whose performance is well known and predictable. Further, it has been recognized that enhancement measures may lead to changes in ecosystem structure and processes. However, while there is need for caution these issues should not be used as a mechanism for restricting development as long as the changes are acceptable to immediate stakeholders and society at large. The maximization of sustainable societal benefits should be the principal objective of enhancements.

Inland open waters like rivers and reservoirs which face massive alteration to the aquatic ecosystem due to demands from various sectors urgently require an effective and integrated management to ensure that their potential values to fisheries and other sectors are maintained. This urgency has been recognized by the Ramsar Convention, under which a few particularly valuable wetland environments are protected as nature reserves.

The emerging participatory approach to management (including co-management) mentioned earlier is essential for ensuring greater success rates in case of interventions including enforcement of conservation techniques. Developmental activities will be more effective and sustainable if the resource users assume the responsibilities and costs of management. However, governments should retain a role in initiating and implementing such schemes. They also have a major role to play in providing and enabling the legal, institutional and mediating framework for their continuation. The assignment of property rights and limitations of access (e.g., gear licensing system) are preconditions for sustainable development and management of inland fisheries. NGOs can play an important part in promoting participation and in safeguarding equitable distribution of the resulting benefits. They may also have an important catalytic role in the transition from government ownership to community based or private management.

In order to meet the conflicting management objectives of increasing fish production and non-deprivation of poor landless fishers of their livelihood, separate areas may be demarcated for pen/cage aquaculture while keeping sufficient areas for capture or culture-based fisheries in certain suitable water bodies like floodplain wetlands (*beels*). If planned properly along the lines of the integrated coastal zone management (ICZM) concept, it may be possible to allocate even separate areas for conservation of fish stocks (e.g. artificial reefs) and migratory aquatic birds (e.g. closed areas).

CONCLUSION

The present concepts of the process approach and responsible management has arisen out of experiences with scientific development and management of fisheries and aquaculture over the past century. Sustainable (ecological, economic as well as social) development and management of the living aquatic resources remains the ultimate goal of both the concepts. How best we achieve the twin objectives of increasing fish production from our inland fisheries as well as the conservation of the environment and biodiversity will depend on improved and rational management. Experiences on development and management of inland fisheries world-wide have shown that with proper planning and participation of all stakeholders in the management process, the balance between these two apparently conflicting objectives can be maintained. However, presently, there is need for following a precautionary approach in situations where this balance may have to be maintained in the face of inadequate knowledge, uncertainty and limited resources. In such situations, actions should be preceded by adequate planning and risk (ecological, genetic and socio-economic) assessment.

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ADVANCES IN ENHANCEMENT AND CULTURE-BASED FISHERIES

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INTRODUCTION

Enhancements are intervention in the life cycle of common pool aquatic resources. They include culture-based fisheries, habitat modifications, fertilization, feeding and elimination of predators/competitors. Under certain conditions, limited technological intervention by man can substantially increase the utilization of natural aquaculture productivity. This is the rationale for enhancements. Enhancement techniques provide opportunities in particular for resource-poor sections of inland and coastal resource users. Enhancement initiatives can facilitate institutional change and a more active management of aquatic resources, leading to significant productivity, conservation and wider social benefits. Introduction of enhancement technologies in common pool resource users may also facilitate institutional changes leading to more efficient and sustainable exploitation of resources.

Enhancement combines attributes of aquaculture (intervention in the life cycle of aquatic organisms) and capture fisheries (exploitation of wild stocks) in a unique way. Even though the technological interventions may be limited and relatively simple (*e.g.* stocking of seed fish), the degree of management control over enhancement outcomes is inherently restricted. This is a consequence of:

a) limited nature of interventions in the ecosystem which is not managed primarily for fish production, and
b) common the pool nature of the resources.

Common pool resources are exploited jointly by separate users, resource use by one individual subtracts from the use of others, and the exclusion of users is difficult to predict.

Enhancements may help to maintain abundance of community structure and ecosystem functioning in the face of heavy exploitation and/or environmental degradation. Negative environmental impacts may arise from ecological and genetic interactions between enhanced and wild stocks. Many enhancements have not realized their full potential because of failure to address the specific institutional, technological, Firstly, enhancements constitute investments in common pool resources and can be sustained under institutional arrangements that allow regulation of use and flow of benefits to those who bear the costs of enhancements. Secondly, technological interventions are limited to certain aspects of life cycle of stocks and outcomes are strongly dependent on natural conditions beyond management control. Hence, management interventions must be adapted to local conditions to be effective, and certain conditions may preclude successful enhancement altogether. Governments have a major role to play in facilitating enhancement initiatives through the establishment of conducive institutional arrangements, appropriate research support and the management of environmental and other external impacts on and from enhancements.

TECHNOLOGIES

- Stocking to create culture-based fisheries. i.e. fisheries based predominantly on the recapture of stocked fish
- Stocking to enhance or supplement self recruiting populations
- Habitat modification to improve levels of requirement and/or growth
- Elimination of unwanted species
- Fertilization
- Combination of the above

Enhancements are estimated to yield about 2 million t per year, mostly from culture based fisheries in freshwaters where they account for 20% of capture or 10% of combined capture and aquaculture production. Contributions to fish production of enhancements other than culture-based fisheries are poorly documented.

CULTURE-BASED FISHERIES

When the fish catch depends entirely or mainly on stocking, it is called *culture-based fisheries*. Although nearly half of the Indian reservoirs (in area) are suitable for development as culture-based fisheries, progress made in this direction is not very satisfactory. In the first place, adequate scientific advice has not been developed for the purpose. Again, the work being done at the research organizations has not percolated down to the level of reservoir managers. The key management parameters involved in the culture-based fisheries are:

a) estimation of yield potential
b) selection of species
c) stocking density , and
d) stocking-harvesting schedule

Assessment of fish yield potential

Estimation of fish yield potential of reservoir is essential for setting many management parameters. Since it is difficult to assess the primary productivity of all reservoirs in the country for macro-level planning, it is necessary to make some rough estimates through indirect means. Several methods are in vogue to assess the fishery potential of reservoirs by deriving equations based on reservoir area, depth, catchment area and the chemical parameters of soil and water. Morpho-edaphic index (MEI) is one of the methods, that use easily available parameters reflecting morphometric as well as chemical characters. Relationships between MEI and catch are based on some common characteristics for sets of lakes that possess a certain number of limnological conditions. These are the ionic composition being dominated by the carbonate-bicarbonate system, the water body being not dystrophic, the volume not fluctuating noticeably and the temperature regime being similar. Indian reservoirs, by and large, fulfil all the conditions except the one on fluctuations in volume. Henderson and Welcomme (1974) have calculated morpho-edaphic index and fish yield potential for African lakes as:

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

$$\text{Fish yield (kg/ha)} = 14.3136 \text{ MEI}^{0.4681}$$

Although the Asian reservoirs are known to have a lower yield potential, till an Indian model is derived, this formula can be applied to the Indian reservoirs to obtain a rough indication of productivity. However, the actual fish yields from most of the reservoirs are much lower than the potential estimated using the formula (Table 1).

Table 1. Estimated fish yield potential and actual yield in seven reservoirs in India

Reservoir	Estimated yield potential(kg/ha) via MEI method	Actual yield (kg/ha)
Stanley (Tamil Nadu)	51	12
Nagarjunasagar (Andhra Pradesh)	48	06
Ukai (Gujarat)	67	46
Rihand(Uttar Pradesh)	27	05
Gandhisagar(Madhya Pradesh)	52	08
Getalsud (Bihar)	68	02
Pong (Himachal Pradesh)	33	32

(After Sugunan, 2000)

Specific selection

Stocking of reservoirs with fingerlings of economically important fast growing species to colonize all the diverse niche of the biotope has become one of the necessary prerequisites in reservoir fishery management. The basic principles that should be followed in selecting a species to be stocked are (Jhingran, 1988):

1. The planted species should find the environment suitable for survival and growth.

2. They should be a quick growing, highly productive herbivorous fishes with shorter food chain and efficiency in food utilization.

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

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

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

However, evaluation of an array of factors like the biogenic capacity of the environment, growth rate of the desired species and the density as regulated by predatory and competitive pressures are needed to be considered before stocking. The policies and guidelines currently available on the subject are still erratic and even arbitrary.

Stocking rate

Stocking densities need to be fixed for individual water bodies or a group of them sharing common characteristics such as size, presence of natural fish population, predation pressure, fishing effort, acceptable marketable size, amenability to fertilizing and multiplicity of water use. The main considerations in determining the stocking rate are growth rate of individual species stocked, the mortality rate, size at stocking and the growing time. Recently, based on the National Consultation on Reservoir Fisheries (Sugunan, 1997), the Government of India has adapted the following formula (Welcomme, 1976) to calculate the stocking rate for small reservoirs:

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

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

P can be estimated through MEI method and the range of mortality rates can be found out from the estimated survival rate. Table 2 illustrates calculation of stocking rates using the formula given above, when P = 200 kg/ha, q = I, W = 0.5 kg and $t_c - t_o$ is 1. The model assumes insignificant breeding by stocked population and therefore applies mainly to total cropping situations *i.e.,* those in which fish are caught below their minimum size for maturity, those whose natural reproduction does not take place and those where water body is not permanent. It shows that stocking density, which depends on the natural conditions of productivity, growth and mortality, are very sensitive to z. Because of the very large numbers of fry needed, this formula may have very limited utility in large reservoirs.

Table 2. Calculated stocking density at different levels of mortality (adopted from Welcomme, 1976)

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

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

Modeling approach

Management of culture-based fisheries implies optimization of stocking and harvesting regime to exploit given natural productivity. This involves management inputs in the form of stocking, natural phenomena like growth and mortality and outputs in the form of fish production. The key management parameters here are stocking density, fishing efforts and gear selectivity (Fig.1). The process of population assessment in case of culture-based fisheries differs considerably from that of capture fisheries. For instance, in case of capture fisheries the recruitment is not under the control of the manager, whereas in culture-based fisheries, it is under control in the form of stocking. Similarly mortality is constant in capture fisheries while it is size dependent in culture-based systems (Table 3).

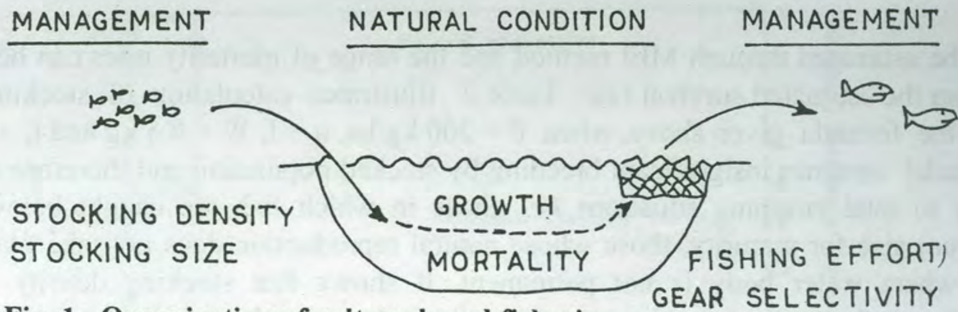

Fig. 1. Organization of culture-based fisheries.

Table 3. Parameters in culture-based and capture fisheries population models

Process	Conventional capture fisheries models	Models for culture-based fisheries
Recruitment	Uncontrollable(density-dependent, stochastic)	Controlled(stocking)
Growth	Density-dependent	Density dependent
Mortality	Constant	Size-dependent (Density-dependent?)

Fish Stock assessment based on population dynamics has received considerable attention in the recent past on account of the increasing popular use of computers. However, much of these studies are related to the wild populations of the oceanic and inland waters. Stock-recruitment relationship is a useful tool in the management of natural populations, as recruitment is beyond the control of managers. Conversely, in a culture-based fishery, the manager can choose the number of fish seed and the time of its stocking. Thus, the recruitment and the growing period (growth) can be controlled, if the role of stocking density and size of seed in determining the growth and mortality are established. In such a system, the mathematical models for density dependent growth and size dependent mortality are important tools for the assessment of stocking and harvesting regimes. In India, no work has been done on the population dynamics and management models applicable to the culture-based fisheries, some work in this direction has been initiated abroad.

It was well known since long (e.g., Beverton and Holt, 1957; Le Cren, 1958; Backiel and Le Cren, 1978; hanson and Logget, 1985; Salogaeri and Mutenia, 1994) that growth of fish is dependent on population density. Similar trend was established in case of extensive aquaculture as well (Walter, 1934; Swingle and Smith, 1942; Pillay, 1990). Nevertheless, no attempt has so far been made to use this tool as an effective aid in management of culture-based fisheries, except for the work done by Lorenzen (1995, 1996a, 1996b) and Lorenzen *et al.* (1997) who tried to develop empirical models (based on Walter, 1934) and mathematical modeling based on the von Bertalanffy's model for density-dependent growth (Beverten and Holt, 1957) for use in extensive aquaculture. He has shown that the dynamics of stocked fish population are determied by two processes *viz.*, individual growth and mortality. Since fish depend entirely on natural food supply, individuals compete for a limited food resource and consequently their growth is dependent on population density. Growth in the model population can be described a density dependent extension of the von Bertalanffy's growth function, where the asymptotic length L_α is a linear function of population biomass:

$$L_{\alpha B} = L_{\alpha L} - dB$$

Where $L_{\alpha B}$ is the asymptotic length of fish growth curve at biomass B, and $L_{\alpha L}$ is the limiting asymptotic length, which a fish would approach in the absence of competition. Even in the absence of competition, the asymptotic length of fish is limited by the natural productivity of the water body, which is thus reflected in $L_{\alpha L}$. The competition coefficient d is the amount by which $L_{\alpha B}$ decreases per unit of population biomass. Mortality rate in the model will be estimated followed the model first proposed by Gulland (1987):

$$M_L = M_r(L/L_r)^{-3\varepsilon}$$

Where M_L is the mortality rate at body length L, and M_r is the mortality rate at reference length L_r. The exponent of the mortality length relationship is -3ε, and ε is the exponent of the corresponding mortality-weight relationship in isometric growth. Representation of the mortality size relationship as a power function was derived theoretically by Paterson and Wroblewski (1984) and there is a substantial empirical evidence for this form of relationship in the marine pelagic ecosystem (McGurk, 1986, 1987).

Attempts to develop a model for culture-based fisheries of reservoirs were made by Lorenzen (1995, 1996a, 1996b) and Lorenzen *et al.* (1997) in nortrheastern Thailand and China. Management models will enable assessment of the responses of model populations in a reservoir to various stocking and harvesting regimes. Relations can be explored separately for stocking density and size at stocking and size of seed. For instance, influence of stocking density on production and recapture rate of stocked fish can be arrived at (Fig. 2). At a fixed fish seed and size at capture, there is a certain level of stocking density, beyond which both production and biomass harvest decrease. The model can also indicate the recapture rate at different stocking rates and production levels. This enables us to determine the optimum level of stocking, based on stocking density and recapture rate at various options on seed size and size at capture. It has been shown by the models constructed elsewhere that moderate overstocking results in sub-optimal production due to slow growth and high mortality, but the fishery can still operate. If stocking density is increased further, the asymptotic length ($L_{\alpha B}$) of the population will fall below the gear selection length (L_c). This means catch will drop to zero, the water body will be literally choked with fish,

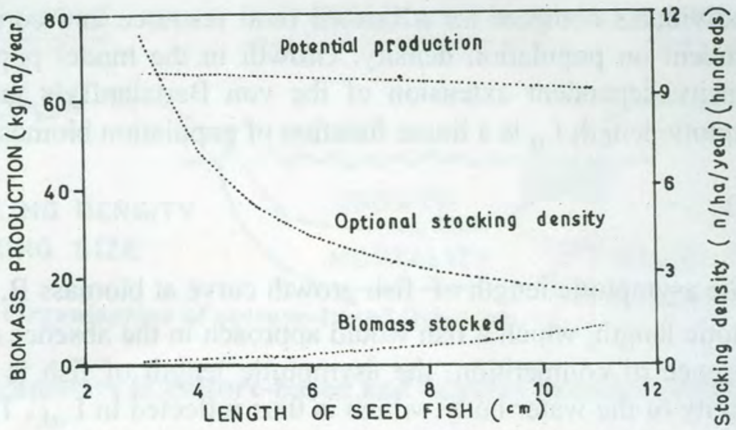

Fig. 2. Influence of length of seed fish on potential production, optimum stocking density and corresponding biomass

resulting in dense stunted population. The production also depends on the size at capture. Smaller the size at capture, higher are the production rates. Using the model, the maximum yields at different sizes at harvest can be estimated, based on the stocking density and seed size. In hypothetical situation (Fig. 3) the fish caught at 40 cm gives a maximum yield 35 kg /ha at a low stocking density of about 140 no/ha/year. At this seed size, if stocking density is increased beyond this limit, production declines sharply and at one stage, totally collapses at about 230 nos/ha. Higher production rates are indicated at a capture size of 35 cm with a higher stocking density and so on. Maximum production is obtained at capture size of 25 cm. However, it has to be seen whether fish can be marketed or fish is accepted by the community at this size. At a higher gear-selection length of 40 cm, the critical biomass is reached easily and overstocking can become a serious management problem. Thus, it is necessary to arrive at size at capture and stocking density based on the minimum size of acceptability.

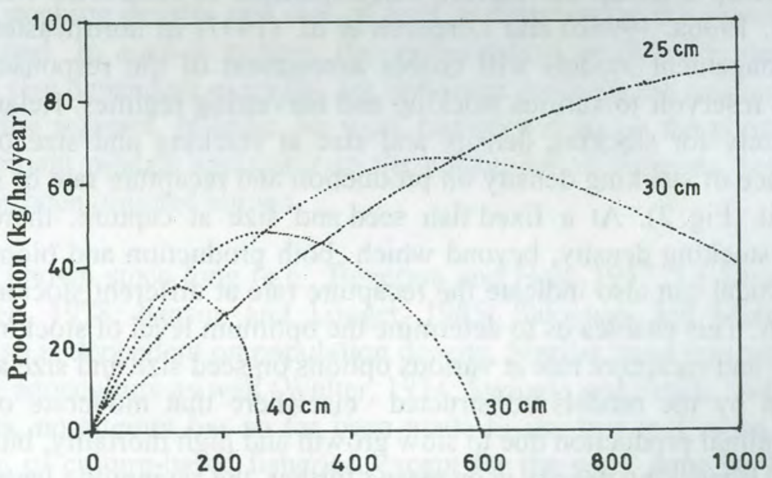

Fig. 3. Production as a function of stocking density for four gear-selection lengths

Combined effect of fishing mortality and stocking density can also be arrived at. This will enable the scientist to determine graphically the point of overstocking and over fishing (Fig. 4) and advise the fishery manager accordingly. Influence of size of seed is also equally important. With the help of models, it has been proved that the optimum stocking density at which potential production is achieved declines sharply with the increase in size of seed. In an example, the stocking density of 1100/ha is necessary to achieve the potential production when seed size is 3 cm, while the same production can be achieved with a stocking rate of 300/ha, if size of seed is 11 cm. Increasing the size of the seed from 3 to 5 cm reduces the number of seed required by more than 50%, while an increase in size from 9 to 11 cm reduces the numbers required by only 15%. Thus, there is need to strike a balance between the need to produce vast numbers of individuals, and the need to rear them to a larger size.

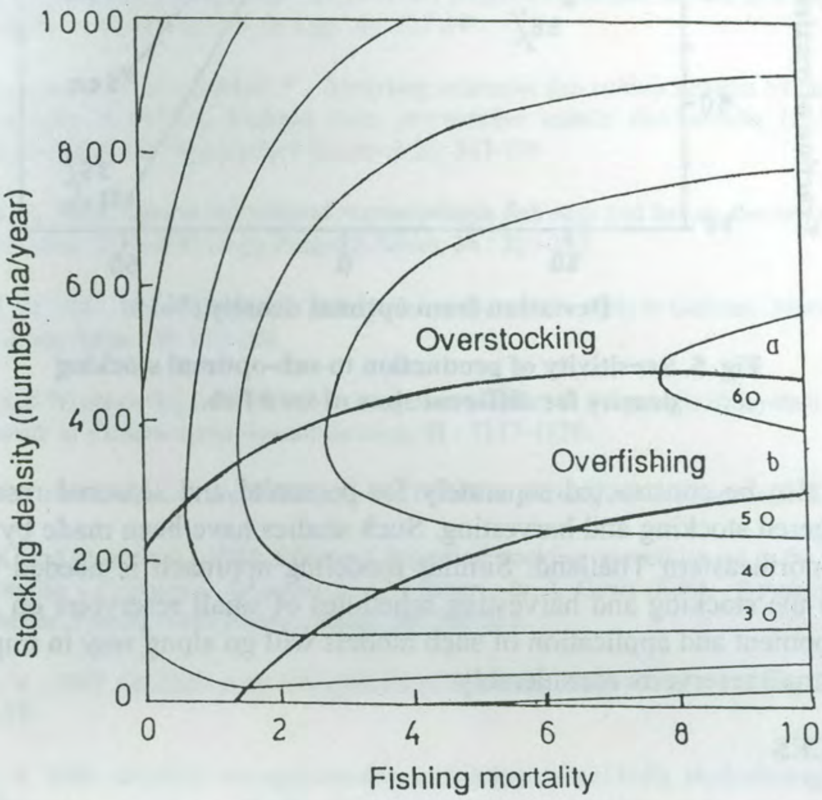

Fig.4 :- Production as function of fishing mortality and stocking density for a gear selection length of 30 cm.
(Contour lines indicate yield in kg/ha/year, Lorenzen, 1995)

Another important feature of the modeling approach is to compare the production loss due to over and under stocking at different seed sizes. It has been shown that when the seed size is 3 cm, 50% overstocking resulted in realizing 88% of the potential production, while 50% under stocking resulted in realizing 80% of the production. The difference in production loss was marginal. However, similar exercise with seed size of 11 cm showed that 50% overstocking produced 35% of the potential as against 66% at 50% under stocking (Fig. 5). This shows the enormous production loss due to overstocking when the seed size is higher. This is particularly important in view of the common tendency of stocking more fingerlings at higher size in culture-based fisheries of reservoirs in India.

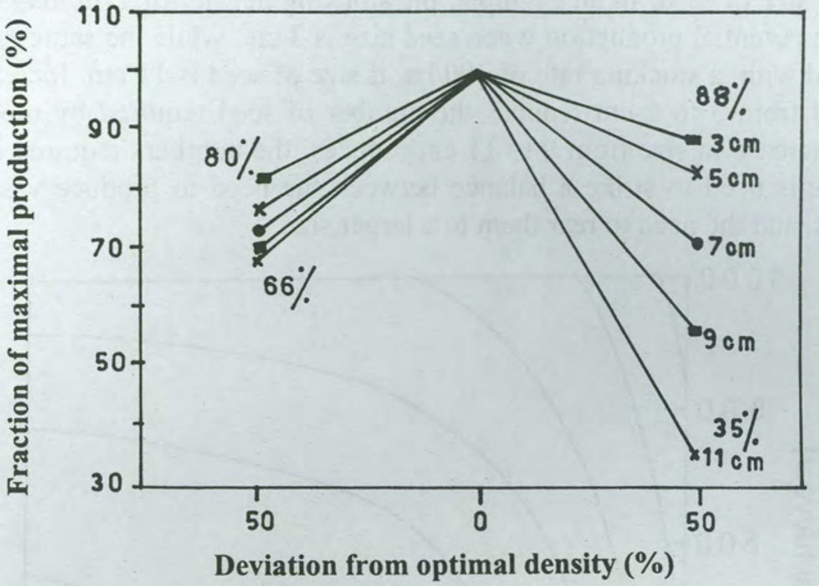

Fig. 5. Sensitivity of production to sub-optimal stocking density for different sizes of seed fish.

Models can also be constructed separately for perennial and seasonal reservoirs and also for staggered stocking and harvesting. Such studies have been made by a group of scientists at northeastern Thailand. Similar modeling approach is needed in India in order to plan the stocking and harvesting schedules of small reservoirs on a scientific basis. Development and application of such models will go along way in improving the yields from small reservoirs considerably.

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