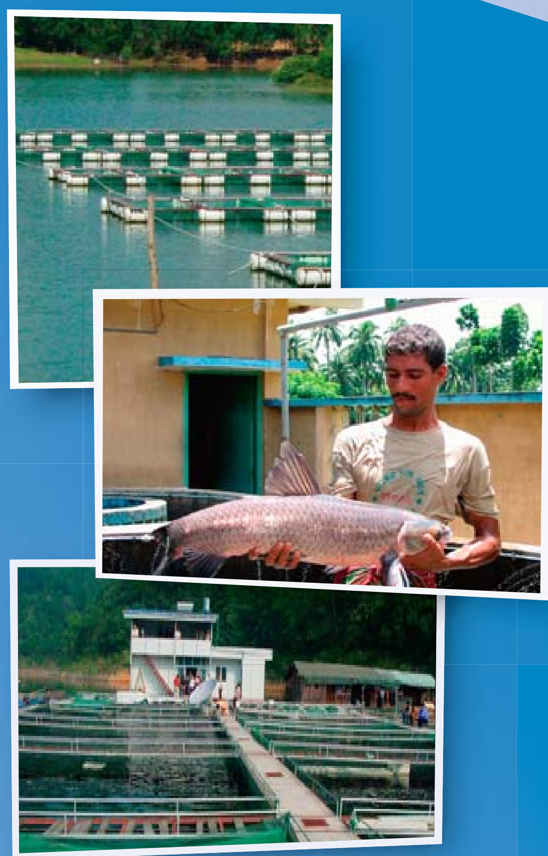
Status of Reservoir Fisheries in Five Asian Countries

China - India - Nepal - Sri Lanka - Thailand



Status of Reservoir Fisheries in Five Asian Countries

Edited by Sena S. De Silva and Upali S. Amarasinghe

Contributors

Miao Weimin
Freshwater Fisheries Research Centre, P.R. China

Jiashou Liu, Zhongjie Li and Songguang Xie
Institute of Hydrobiology, P.R. China

K.K. Vass
Central Inland Fisheries Research Institute, India

V.V. Sugunan
Indian Council of Agricultural Research

Gagan B.N. Pradhan
Directorate of Fisheries Development, Nepal

Upali S. Amarasinghe
University of Kelaniya, Sri Lanka

D.E.M. Weerakoon
National Aquaculture Development Authority of Sri Lanka

Tuantong Jutagate
Ubon Ratchathani University, Thailand

NACA MONOGRAPH SERIES
NACA is an intergovernmental organisation that promotes rural development through sustainable aquaculture. NACA seeks to improve rural income, increase food production and diversify farm production. The ultimate beneficiaries of NACA activities are farmers and rural communities.

Visit NACA online at www.enaca.org for hundreds of freely downloadable publications on aquaculture and aquatic resource management.

PO Box 1040, Kasetsart University Post Office
Ladyao, Jatujak
Bangkok 10903
Thailand
Email: info@enaca.org

De Silva, S.S. and Amarasinghe, U.S. (eds.). (2009) Status of reservoir fisheries in five Asian countries. NACA Monograph No. 2. Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand. 116p.

Foreword

The Icelandic International Development Agency (ICEIDA) and NACA have been partners in the project “Strategy for Asian Reservoir Fisheries Development and Management” since 2006, when a Memorandum of Understanding was signed.

Historically, fisheries is an important element in the foundation of the Icelandic economy, and the rich fishing grounds in Icelandic waters are unquestionably the platform that enabled the nation to move from poverty to prosperity in the 20th century. This is also reflected in the focus in bilateral cooperation of ICEIDA.

After substantial growth in capture fisheries after the Second World War, the rate of growth was significantly reduced in the 70s and into the 80s. For the past three decades or so, world capture fisheries have fluctuated around 90 million tons annually, in spite of increased fishing pressure. Mismanagement and environmental changes now threaten a large number of fisheries, leading to a crisis of global proportions which calls for a move towards more responsible fisheries and better utilisation of the catch. It is clear however that the increased global demand for fish has become and will continue to be dependent on an increase in aquaculture and fish farming. To meet this challenge, further global investments need to be made in research and development.

Iceland and Sri Lanka launched bilateral development cooperation in 2005 with the joint aim of positive developments in the Sri Lanka’s fisheries sector. The partnership initially focused on aspects of quality and management in capture fisheries, but realising the importance of freshwater fish farming in Sri Lanka and the abundance of inland waters suitable for aquaculture, efforts in those areas would be welcomed when opportunities arise.

The dialogue on ICEIDA support to aquaculture development in the Asia-Pacific region started between the ICEIDA Country Office in Sri Lanka and NACA in late 2006, with positive support from ICEIDA’s bilateral partner, Sri Lanka. Discussions soon focused on the possible involvement and financial support from ICEIDA to a regional project, developed by NACA, addressing reservoir and lake fisheries management in the NACA member states. The framework for the project was approved by all concerned parties and launched in August 2007, with the first planning meeting held in NACA headquarters in Bangkok, in January 2008.

The proceedings from that first project planning meeting presented in this publication are a testimony to the commitment of NACA and the participating member countries to the project and regional cooperation in general. This is an encouragement to ICEIDA for continued support to development of regional cooperation in fisheries and aquaculture. ICEIDA will continue to follow the progress in the project with interest and is committed to support positive efforts in future developments when opportunity arises.

Arni Helgason, Country Director
ICEIDA Country Office, Sri Lanka

Contents

Foreword i

Introduction 1

Development of Reservoir Fisheries in China 3

Achievements, Challenges and Strategies for Reservoir Fisheries
Development in China 17

Status of Reservoir Fisheries in India 31

Reservoir Fisheries in Nepal 55

Present Status and Future Strategies for the Management of
Reservoir Fisheries in Sri Lanka 69

Reservoir Fisheries of Thailand 99

Introduction

Reservoirs are rarely and or never created for fishery purposes. However, the secondary use of the impounded waters for fisheries is becoming an increasingly important activity, particularly in Asia, the region that is purported to have the highest reservoir acreage amongst all continents. Reservoir fish production is also gradually becoming a significant contributor to total inland production, and often provides a relatively affordable source of fresh and good quality animal protein source to many rural communities, as well many livelihood opportunities directly and indirectly.

Reservoir fishery activities in the recent past are also seen as a means of providing alternate livelihood opportunities to people that are displaced by the impoundment. Such livelihoods could entail engagement in capture fisheries and or aquaculture activities such as cage culture. In addition, nations are beginning to take note of the vast reservoir resources that are of a non-perennial nature in the Asian region for development of culture based fisheries. This development, a low cost community activity, is thought to provide significant subsidiary income to downstream farmers and contribute to their nutrition.

Notably in the region the reservoir fish fauna, fisheries production and management methods, amongst others factors, differ widely. The differences in fish yield between reservoirs and/or between countries cannot be easily understood and are unlikely to be determined by individual parameters or characteristics such as the reservoir fish fauna, water quality criteria, hydrological regimes, morphometry, management patterns and so forth. However, it is possible that there is a great deal to be learnt from management practices of each country. In the above context and in view of the increasing importance of reservoir fisheries in the region it was considered appropriate to take stock of the current status thereof, with a view to utilising this knowledge to develop and or evolve appropriate national and or regional strategies for sustained development of reservoirs fisheries.

This volume attempts to fulfil the above objective, and accordingly as a first step brings together reviews of the current status of reservoir fisheries, of China, India, Nepal, Sri Lanka and Thailand, all countries in which reservoir fisheries play a major role in fish production and rural livelihoods.

Sena S. De Silva and Upali S. Amarasinghe

Development of Reservoir Fisheries in China

Miao Weimin
Freshwater Fisheries Research Centre, Chinese Academy of Fisheries Science, 214081, P.R. China.

Introduction

China has a long history of reservoir fisheries activities. The earliest stocking activity of fish seed collected from rivers took place in Dong Qian Hu reservoir which was impounded some 1000 years ago in Zhejiang province (Shi, 1996). Many reservoirs have been constructed in China since the 1950s for various purposes and are also used as important resources for fisheries development. Presently, reservoir fisheries have become an important component of the fisheries industry in China, and make a substantial contribution to people's fish supplies and rural livelihoods.

China is currently in a new development stage. Environmental conservation and wise use of resources are of major concern in development activities. There is a great potential for reservoir fisheries development in China but challenges also exist.

Reservoir resources

Nature of reservoirs

Reservoirs were constructed by the ancient Chinese, mainly for the purpose of regulating rain water for crop irrigation. The earliest reservoir in China, Dong Qian Hu, was constructed about 1000 years ago in Zhejiang Province. However, there were only about 20 reservoirs in the whole of China until 1949 when the People's Republic of China was founded. Since the 1950s, numerous reservoirs of different sizes have been built in China for the purposes of flood control, irrigation and hydropower generation.

In China reservoirs are usually divided into three categories, *viz*. valley type, branch type and plain type, according to the geographic characters of the locations. The valley type is normally constructed in the upper reaches of the river at a high altitude. It often has a high current velocity, high turbidity and a short water retention period, and is mainly used for hydropower generation. The branch type of reservoir is located in hilly areas. It is characterised by a large number of islands and coves inside the reservoir. The plains type of reservoir is usually constructed in the plain areas at low altitudes. It features relatively shallow water and broad basins with an extensive water surface.

Currently, there are some 85,108 reservoirs in China (Ministry of Agriculture, 2006) with a total water surface area of approximately 2.302 million ha (Bureau of Statistics, 2007) and a total storage capacity of 562.38 billion cubic metres (Ministry of Agriculture, 2006). There has been a considerable increase in the number and storage capacity of reservoirs in China during the past 10 years, particularly of the large and medium sized reservoirs. Reservoirs compose a very important part of inland water resources (about 13% of inland water resources; Figure 1) in China. Lakes and ponds also form about 56% of inland water resources.

In addition to the classification based on geographical character, Chinese reservoirs are also classified into three categories according to their storage capacity, i.e., large, medium and small. Numerically, small reservoirs dominate the total reservoir resources in the country, but the highest storage capacity is registered for large reservoirs (Table 1).

Figure 1. Categories of inland water resources in China (in thousand ha) (Bureau of Statistics, 2007).

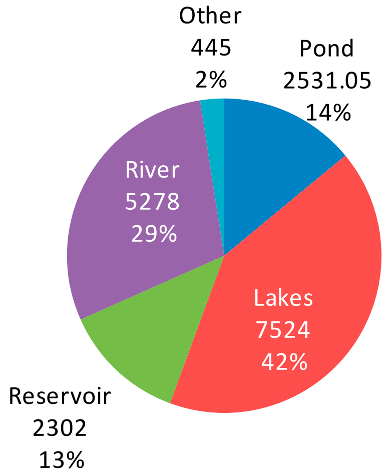


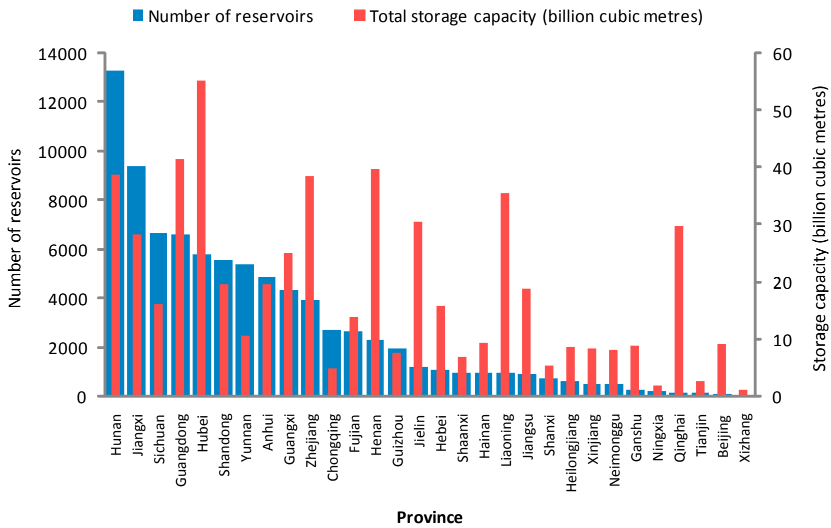
Table 1. Number and total storage capacity (billion m³) of reservoirs of different sizes (Ministry of Agriculture, 2006).

Size	Storage capacity (million m³)	Number	Total storage capacity
Large	>100	470	419.66
Medium	10-100	2,934	82.57
Small	<10	81,704	60.15
Total		**85,108**	**562.38**

Distribution of reservoirs

In general, reservoirs are distributed throughout the country. Every province, autonomous region and municipality directly under the central government (MDUCG) has reservoirs of all categories within its jurisdiction in the mainland of China except Shanghai. However, the distribution of reservoirs across the country is quite uneven in terms of number and size. The total number and storage capacity of reservoirs in each province/autonomous region/MDUCG (Figure 2) indicate uneven distribution of reservoirs in the country.

Figure 2. Total number and storage capacity of reservoirs in each province / autonomous region / MDUCG (Ministry of Agriculture, 2006)



Potential of reservoir fisheries development

China lies across a range of climatic zones and reservoirs are also located in areas of different climatic, geographic and topographic conditions. As such the potential of reservoirs for fisheries development varies between locations and individual reservoirs.

Reservoirs in the northeastern China have the highest fertility due to high organic content in the soil of the watershed area. However, due to the long winter with very low temperature in this region, growth of fish and other aquatic animals is slow. Nevertheless, the productivity is still higher in the reservoirs of this region than in reservoirs of most other parts of China. Fish production in many reservoirs in the area can reach 230 kg ha^{-1} $year^{-1}$ (Shi, 1996). Reservoirs located in the lower reaches of Yangtze River are also highly productive. For instance, average annual fish yield of all reservoirs (except XinAnJiang Reservoir) in Zhejiang province reached more than 270 kg ha^{-1} $year^{-1}$ from natural and aquaculture-based fisheries. In comparative terms, productivity of reservoirs located in Loess Plateau and the western part of China is much lower than those in other areas due to various reasons such as high water turbidity, low water temperature in high altitudes and high salinity. Although the capture fisheries production of reservoirs in southern China is not very high, high temperature and long growing period of fish greatly facilitate cage culture in these reservoirs.

The valley type reservoirs have very limited potential for fisheries development mainly due to the high current velocity, high turbidity and short water retention period. Branch and plain type reservoirs are usually built in the middle and lower reaches of rivers at the low altitudes and the environmental conditions of these reservoirs are more or less stable. Also, they are biologically productive. As such, these reservoirs are suitable for fisheries development.

Biological characteristics of reservoirs

Natural food organisms

The availability of natural food organisms in reservoirs is the most important basis for fisheries production. Planktonic organisms are the most dominant food organisms in all reservoirs. In many reservoirs, phytoplankton abundance usually ranges between 5-10 mg l^{-1}. In Fengman reservoir (a mega reservoir in Jilin province) plankton biomass was as high as 10.86 mg l^{-1} (Zhang, 1986). In smaller reservoirs, the phytoplankton biomass can be much higher. For example, mean phytoplankton biomass in Kunlong Reservoir (188.7 ha) in Shandong province is 20.57 mg l^{-1} (Xing, 2007). On the other hand, and as expectedly, zooplankton biomass is lower, and in Fengman reservoir was 6.63 mg l^{-1} (Zhang, 1986). Overall, however, and compared to other kinds of inland water bodies, zooplankton biomass is much higher in reservoirs. Zooplankton biomass in Kunlong reservoir was 19.48 mg l^{-1} (Xing, 2007). Benthic animals are another important group of food organisms in reservoirs. Benthic biomass was 9.1 g m^{-2} in Fengman reservoir (Zhang, 1986) and 3.34 g m^{-2} in Guanyingge reservoir (Shi, 2006).

Reservoir fish fauna

The information on the fish fauna of Chinese reservoirs is relatively limited. Generally, reservoir fish fauna are less complex than other inland water bodies, particularly lakes. This might be due to specific hydrological characteristics in reservoirs. Since reservoirs in China are located in different geographic and climatic zones, fish fauna in different reservoirs also vary greatly. The fish fauna in a reservoir in Liaoning province of northeast China is reported to include 29 species belonging to nine families (Liu, 2003). Of these, 21 species belong to family Cyprinidae (Table 2).

In contrast, in another Chinese reservoir (You Xi Jie Mian reservoir) in Fujian province of southern China, there are 84 species of fish of 15 families (Chen, 2006). These include 50 species of Cyprinidae, five species of Cobitidae, seven species of *Siniperca* spp. and eighteen species from eleven other families. The common economically important species include grass carp, silver carp, bighead carp, common carp, crucian carp, *Xenocypris* spp. loach, *Opsariichthys bidens* (Gunther) and *Hemigymnus* spp. These two examples indicate that obvious differences can be found in the fish fauna of Chinese reservoirs in different locations.

Introduced fish species

As an effort to improve fish faunal composition in reservoirs for better utilisation of natural productivity, introduction of fish species has been extensively carried out in Chinese reservoirs since the 1950s. However, the species used are limited to introductions being mainly across different watersheds. Several translocated species such as grass carp, silver carp, bighead carp, *Protosalanx hyalocranius* (Abbott), *Megalobrama amblycephala* (Yih), *Hypomesus olidus* (Pallas) and *Plagiognathops microlepis* (Bleeker) have significantly improved fish production.

Introduced fish species play a very important role in reservoir fish production in China. Silver and bighead carp constitute the major share of fish production in most reservoirs in China. Introduction of fish species also significantly expanded the fish fauna in many Chinese reservoirs. Species such as *P. hyalocranius, M. amblycephala*, *H. olidus*, *N. taihuensis* and *P. microlepis* shave established self-propagating populations in many reservoirs.

Table 2. Fish fauna in Beishi reservoir (Liu, 2003; * = introduced species).

Family	Name
Salangidae	*Protosalanx hyalocranius* (Abbott)*
Cyprinidae	*Tribolodon brandtii* (Dybowski)
	Phoxinus lagowskii (Dybowski)
	Ctenopharyngodon idella (Val.)*
	Opsariichthys bidens (Gunther)
	Megalobrama amblycephala (Yih)*
	Chanodichthys erythropterus (Basilewsky)
	Hemiculter leucisculus (Basilewsky)
	Rhodeus sinensis (Gunther) sp.
	Abbottina rivularis (Basilewsky)
	Romanogobio tenuicorpus (Mori)
	Gobio soldatovi (Berg)
	Gobio rivuloides (Nichols)
	Gnathopogon chankaensis (Dyb)
	Pseudogobio vaillanii longirostris (Mori)
	Gnathopogon notacanthus (Berg)
	Saurogobio dabryi (Bleeker)
	Gobiobotia brevirostris (Chen & Cao)
	Cyprinus carpio (L.)
	Carassius auratus (L.)
	Hypophthalmichthys molitrix (Val.)
	Aristichthys nobilis (Richardson)
Cobitidae	*Misgurnus anguillicaudatus* (Cantor)
Bagridae	*Pelteobagrus fulvidraco* (Richardson)
Siluridae	*Silurus asotus* (L.)
Clariidae	*Clarias leather* (Pfeffer)
Odontobutidae	*Micropercops swinhonis* (Gunther)
Gobiidae	*Gobius*. spp.
Channidae	*Ophicephalus argus* (Cantor)

Fisheries

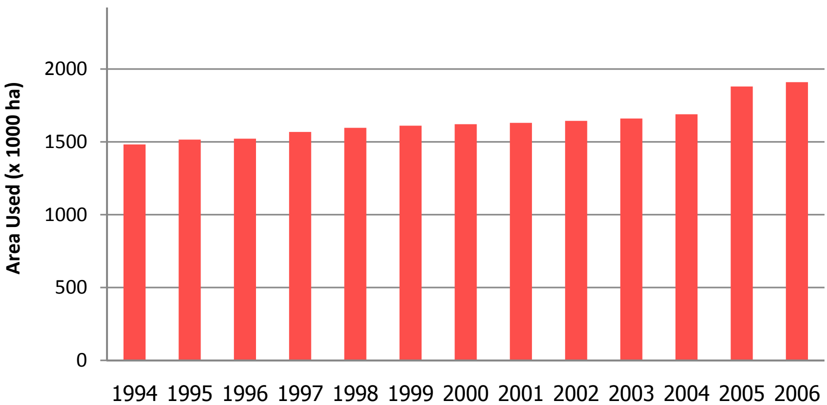
Utilisation of fisheries resources in reservoirs of China

China has a long tradition in managing inland fisheries. In newly constructed reservoirs, fisheries activities usually start immediately after the storage of water. Fisheries development in new reservoirs is also considered to be an effective way to provide new livelihoods to the people displaced during the construction of a reservoir. The economic activities associated with reservoirs include hydropower generation, forestry, fisheries and more recently tourism.

In China, approaches for utilisation of the potential for fisheries development in reservoirs includes capture fisheries, culture based fisheries (extensive culture) and intensive aquaculture. Capture fisheries are usually carried out by individual fishers. Culture based fisheries are usually practiced by community groups, companies or individual families. Intensive aquaculture is usually managed by companies or individual families.

Reservoir area utilised for culture based fisheries in China during 1995-2006 shows a steady growing trend (Figure 3). About 83% of the total reservoir area in China is used for culture-based fisheries.

Figure 3. Reservoir area with culture based fisheries in China during 1995-2006 (Bureau of Fisheries, 1995-2007).

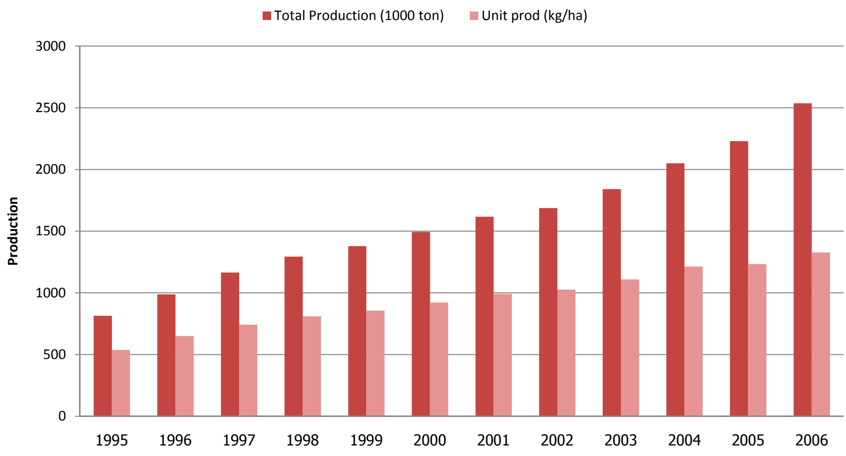


Production levels and trends

Environmental conditions of reservoirs vary greatly in China. There is a great difference in fish yield across the reservoirs. Fisheries management practices and their effectiveness also differ from one reservoir to another. All these result in differences in production level and as such, it is rather difficult to have a clear understanding on the production level of different types of reservoirs. Some well managed reservoir of moderate size and conducive environmental conditions may produce as high as 2 tonnes/ha of fish. For instance, fish production of Huayuan reservoir (246 ha, water depth 19.8 m average) reached 2,032.52 kg/ha in 2004 (Gao, 2006). However, fish production is less than 100 kg/ha in many large reservoirs in China.

In the past few decades, there has been considerable improvement in reservoir fisheries management in China, mainly improved stocking practices and better management in fishing activities. These resulted in significant increases in production. This is exemplified by the steady increase of unit production during 1995-2006 in reservoirs that practice culture based fisheries (Figure 4). However, trends in fish yields from capture fisheries are not known due to lack of statistical data.

Figure 4. Total and unit production from reservoir culture based fisheries in China during 1995-2006 (Bureau of Fisheries, 1996-2007).



Undoubtedly, increased reservoir fisheries production in China has contributed significantly to national fish production. However, the exact overall contribution of reservoir fisheries in general to the total fish production is not known as the inland capture fisheries production in China includes capture fisheries from lakes as well as from rivers. Production from culture based fisheries in reservoirs during 1995-2006 (Figure 4) demonstrates the increasing trend.

Jurisdiction of reservoir water and fishery resources

In China, all natural resources including water resources in reservoirs belong to the state. Water resources in reservoirs are managed by the irrigation authority of the government. Nevertheless, the jurisdiction of fisheries resource is often separated from water resource management. Depending on the size of the reservoir, management mechanisms vary. In large reservoirs, fisheries management authorities are established. Fisheries activities of medium sized reservoirs are often managed by groups of displaced inhabitants in flooded areas or by a company. In small reservoirs, fisheries are managed by groups of people or families.

Main fisheries strategies

As mentioned above, there are three types of reservoir fisheries in China, *viz*. capture fisheries, culture based fisheries (extensive culture) and intensive farming. The fisheries strategies vary according to these three types.

Capture fisheries are usually operated by individual fishers, using small traditional fishing gears such as gill nets, traps of different types, lifting nets (sometimes assisted with light attraction) and floating dragnets. Individual fishers need to be licensed by the reservoir fisheries management authority. These fishers are permitted to fish only naturally recruited species using specified mesh sizes of fishing gear in specified areas.

Culture based fisheries are usually operated by companies/community groups or individual households depending on the size of the reservoir. They are responsible for looking after all production links from stocking, management to harvesting. The fishing operation is usually run on large scale with combined gears such as gill nets, blocking nets, driving nets and set-bag nets.

Intensive culture in reservoirs includes pen and cage culture. Pen culture is practiced mainly in shallow reservoirs. It is usually operated by individual households. Cage culture is commonly practiced in relatively deep water, which takes advantage of good water quality. Cage culture operation varies in scales. It can be operated either by commercial companies or individual households.

Statistical collections

Fisheries statistical data are collected by fisheries administrative authorities at the local level. These statistical data are verified by the statistics agency of the same administrative level before reporting to the higher administrative level. Collection of data in the field is carried out by assigned fisheries staff according to the format designed by the Ministry of Agriculture.

Fisher organisations

Culture based fisheries, which are a common practice in many reservoirs of China, are managed by companies or community groups. Recently, the government has also promoted the establishment of fishers' associations in order to assist individual fishers in marketing and to facilitate management of fishing activities. Of these two types of organisations, companies and community groups are very effective to develop reservoir fisheries, particularly cultured based fisheries. The fishers' associations are still in the process of development. They are expected to play a vital role in reservoir fisheries management in China in future.

Marketing

Fisheries products from reservoirs are marketed in different ways according to the practices and scope of fisheries activities. For fisheries operated by community groups and companies, there are well established marketing channels. They usually have access to distant markets that can bring them better benefits. Community groups and companies often have their own cold storage and processing facilities, which can increase the value of the products. Tourism and restaurant business are also responsible for increase of the value of fisheries products.

Individual fishers in small-scale fisheries do not have access to distant markets where fisheries products could fetch higher prices. The fisheries products in small-scale fisheries are therefore sold to local and nearby consumers. Establishment of fishers' organisations may help small-scale fishers to get better market access.

Socio-economics of reservoir fisheries

Compared to crop farming and forestry, fisheries production can generate relatively higher incomes for rural households. Therefore, average income of fishers is much higher (on the magnitude of about 80%) than the income from agriculture. On the other hand, fishing and aquaculture in reservoirs are relatively tough occupations compared to other economic activities such as agriculture and as such, they are less attractive to the younger generation.

Current research

Since the late 1950s, a considerable amount of research activities have been carried out with the support from central and local governments. Research on reservoir fisheries in China covers the following major areas:

- Investigations on capture fisheries production.
- Environment and ecological studies related to reservoir fisheries, such as the impacts of fishery activities on water quality, role of fisheries in environment restoration and carrying capacity of intensive culture in reservoirs.
- Improvement of culture based fisheries.
- Reservoir fisheries management schemes.
- Intensive culture techniques in reservoirs.

Reservoirs are usually located in remote areas and far from research institutions. Therefore, major production related research is conducted by local fisheries management bodies or extension agencies. Specialised fisheries research institutions tend to focus more on environmental and ecological aspects and key techniques in intensive culture.

Constraints to reservoir fishery development

In the past two decades reservoir fisheries have witnessed rapid developments in China in terms of production. However, their development is facing a number of constraints in the ensuing years.

Physical condition of reservoirs

Global warming and other climatic changes result in irregular rainfall in many areas of China. Frequent instances of low rainfall have caused significant reduction in water area and depth of reservoirs. Soil erosion causes serious soil sedimentation in some reservoirs. These problems significantly reduce the fish productivity in the reservoirs.

Biological and environmental constraints

Eutrophication is a common problem in many inland water bodies in China. Such environmental degradation is caused by numerous factors associated with rapid economic development. Protection and restoration of aquatic environment is of greater concern of the government and the public. Fisheries and particularly aquaculture have become easy targets to be blamed for environmental degradation. More and more strict regulations are imposed on development of aquaculture in inland water bodies including reservoirs. Cage culture has been discontinued in some reservoirs, which are mainly used for water supply in urban areas.

Eutrophication of reservoirs also affects the reservoir fisheries in a number ways. Serious eutrophication alters the species composition of fish communities in reservoirs. Population densities of fish species of high economic value have declined significantly in some reservoirs. Degradation of water quality also affects the growth of fish and feed conversion in cultured based fisheries and aquaculture.

Socio-economic constraints

Presently, culture based fisheries are the main approach to increase fish production in reservoirs. Silver carp and bighead carp are the major constituent species in culture based fisheries production in reservoirs. These two species are however generally considered as low quality fish. High production of these fish species often seriously reduces the market price, which results in low economic efficiency.

In China, large numbers of small and medium size reservoirs are contracted to companies or individual households for better fisheries management. Conflicts arise sometimes between the community groups conducting culture based fisheries and traditional fishers. Illegal fishing and poaching still exist in some reservoirs.

Policy constraints

Reservoir fisheries are a relatively small contributor to the national fisheries industry so it receives very limited attention from the government. In general, reservoirs are located in remote areas where it is relatively difficult to access support systems such as technical extension services and marketing related infrastructure is usually weak. Fishers and aquaculture operators are more vulnerable to natural disasters.

Future strategies

Reservoirs are an important natural resource with multiple uses. Being a country with very high population density, in China the per capita availability of land is low. As a result, land based economic activities such as agriculture have little scope for contributing to furthering the rural economy. Through effective management, economically and ecologically sound fish production is possible from reservoir fisheries. As such, reservoir fisheries can play a significant role in improving fish supply and generating income for the rural population. For the long-term sustainability of reservoir fisheries of China, the following approaches are important.

Development of eco-friendly fisheries in reservoirs

In the past, reservoir fisheries were fish production-centred, when fish supply was inadequate to meet the demand in China. Presently, fish production meets the demand so that environmental concerns are prevalent in reservoir fisheries management to produce fish without adverse impacts on environment. "Water conserving fisheries" has become a concept accepted by more and more people for long-term sustainability of fisheries.

Furthermore, good reservoir fisheries practices will help in coping with degradation of the aquatic environment, particularly eutrophication problems. In future strategies, reservoir fisheries should be studied through ecological perspectives.

Development of leisure fisheries

Reservoirs are generally located in areas with beautiful natural landscapes so that there is a high potential for development of sport fishing and tourism. There have been several good examples where reservoir fisheries were well combined with tourism and holiday business, which significantly improved the economic benefit from reservoir fisheries. Therefore, leisure fisheries should be considered as an important approach to improve the economic performance of fisheries where it is applicable (Huang, 2005).

Improvement of fish species composition in reservoirs

Reservoir fisheries production is presently mainly dependent on silver and bighead carp. Undoubtedly, silver and bighead carp will still remain as important species in reservoir fisheries due to their efficiency in utilising plankton. In addition, other indigenous species should be introduced to reservoirs after careful study to improve the species structure and fisheries efficiency.

Strengthening the support for management of reservoir fisheries

To ensure the sustainability of reservoir fisheries in China, the support system should be further strengthened for effective fisheries management of reservoirs. There is great need to set up new institutional arrangements to coordinate reservoir fisheries development with other concerned partners. Infrastructures such as marketing and transportation need to be improved. In-depth studies on the relation between different fisheries production modes, environment and new techniques for improving ecological and economic benefit of reservoir fisheries should be strengthened.

Improvement of fisheries management mechanisms in reservoir fisheries should include functional zoning of the water bodies, licensing systems for different kinds of fishery activities and better coordination between the interests of different stakeholders. Participation of fishers and farmer organisations in the decision making processes is vital in the improved management strategies.

References

Bureau of Fisheries, 1996. *China Fisheries Statistics Yearbook 1995*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries, 1997. *China Fisheries Statistics Yearbook 1996*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries, 1998. *China Fisheries Statistics Yearbook 1997*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries, 1999. *China Fisheries Statistics Yearbook 1998*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries. 2000. *China Fisheries Statistics Yearbook 1999*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries, 2001. *China Fisheries Statistics Yearbook 2000*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries, 2002. *China Fisheries Statistics Yearbook 2001*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries, 2003. *China Fisheries Statistics Yearbook 2002*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries. 2004. *China Fisheries Statistics Yearbook 2003*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries, 2005. *China Fisheries Statistics Yearbook 2004*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries, 2006. *China Fisheries Statistics Yearbook 2005*. Bureau of Fisheries, Beijing, China.

Bureau of Fisheries. 2007. *China Fisheries Statistics Yearbook 2006*. Bureau of Fisheries, Beijing, China.

Bureau of Statistics, 2007. *China Statistics Yearbook 2006*. China Statistics Press, Beijing, China.

Chen, X., 2006. Practice and discussion on investigation and development of fisheries resources in You Xi Jie Mian Reservoir in Fujian province. *Journal of Fujian Fisheries*, 1: 84-86.

Gao, Y., Xu, Q. *et al*., 2006. Technical measures for continuous high production and efficiency of fisheries in Huanyuan Reservoir. *Reservoir Fisheries*, 26 44-45.

Hu, C. and Huang, D. *et al*. 2005 Study on coordination of fisheries development and multi-functions of large and medium reservoir in China. *Reservoir Fisheries*, 25 (5): 1-4.

Liu Z. and Tang Z. *et al*., 2003. Baseline survey of fisheries resources in Beishi Reservoir. *Reservoir Fisheries*, 23: 43-46.

Ministry of Agriculture, 2006. *China Agricultural Yearbook 2005*. China Agricultural Press. Beijing, China.

Shi, W., 1996. *Fish Enhancement and Aquaculture in Inland Open Waters*. China Agricultural Press, Beijing, China.

Shi, J., Yu,W., *et al*. 2006. Investigation report on fisheries resources in Guanyinge Reservoir. *Reservoir Fisheries*, 26: 109-112.

Xing, Y., Lin, Z. *et al*., 2007. Investigation to plankton in Kunlong Reservoir and analysis on the fish productivity. *Reservoir Fisheries*, 27: 61-62.

Zhang, J., 1986. *Fisheries Resources in Amur River System*. China Agricultural Press, Beijing, China.

Achievements, Challenges and Strategies for Reservoir Fisheries Development in China

Jiashou Liu, Zhongjie Li and Songguang Xie
State Key Laboratory of Freshwater Ecology and Biotechnology, Institute of Hydrobiology, the Chinese Academy of Sciences, 7 South Donghu Road, Wuhan 430072, P.R. China.

Introduction

Aquaculture has been conducted in China for more than 3,000 years, but reservoir fisheries are a new sector in China, which have been growing with the large-scale construction of water projects. More than 86,000 reservoirs have been built in China for irrigation, flood control, power generation and navigation in a little over five decades. As a result, two million hectares of reservoir area suitable for fish production have become available (Wu, 1998). Reservoirs in China are classified into three types based on the surface area: large (surface area > 667 ha), medium (surface area between 67 - 667 ha) and small (surface area < 67 ha). There are more than 400 are large sized reservoirs, about 3,500 are medium sized and more than 8,200 are small sized.

China is densely populated. The construction of reservoir projects has inundated a large area of agricultural land, resulting in the displacement of large numbers of people. In compensation for the loss of agricultural land, the Chinese government emphasised the development of reservoir fisheries to provide alternative livelihoods to displaced people.

In the past 60 years or so, China has made much progress in reservoir fisheries development and management. On the other hand, the development of reservoir fisheries in China has also encountered some challenges. In this paper, the achievements of reservoir fisheries in China are reviewed, the challenges are highlighted and development strategies are discussed with a view to identifying strategies for the sustainable development of reservoir fisheries in China.

Achievements of reservoir fisheries in China

Over the last 60 years when most progress was made in reservoir fisheries development in China, the most important change was the transition from extensive culture to semi-intensive and intensive culture. In the 1950s, the capture of naturally occurring fish populations was the main component of reservoir fisheries. This is still the case in some large-sized reservoirs. In order to rationally exploit the natural fish resources in reservoirs during the early phase of development, some strategies such as introducing fry into reservoirs through diversion of water from rivers, establishing protected areas for the reproduction of fishes, prohibiting fishing in the breeding areas and during the peak recruitment seasons and controlling the size at capture were adopted (Liu and He, 1992). With the success of artificial propagation of the four domestic carps (silver carp *Hypophthalmichthys molitrix*, bighead carp *Aristichthys nobilis*, grass carp *Ctenopharyngodon idella* and black carp *Mylopharyngodon piceus*), stocking of fish into small- and medium-sized reservoirs became a very important fisheries practice. This not only brought about significant economic efficiency, but also helped to employ a lot of displaced people. For example, the fish yield in Fuqiaohe Reservoir, Hubei Province (1,340 ha), increased from 30 tonnes prior to stocking to 300 tonnes after stocking and more than 300 displaced people were employed as fish farmers or fisheries management officials (Liu and Huang 1998). The main achievements of Chinese reservoir fisheries include:

- Rapid increase of fish production in reservoirs.
- Establishment of stocking and fisheries management systems.
- Fish productivity assessment in reservoirs.
- Improvement of capture techniques.
- Improvement of fish escaping avoidance techniques.
- Standardisation and extension of fisheries techniques.

Rapid increase of fish production in reservoirs

Fish yield from reservoir fisheries was only 54,000 tonnes in 1949 when the People's Republic of China was founded. With the liberalisation of the economy in China in 1978, consumption patterns of people changed as a result of increased buying power. Consequently, fish yields from the reservoirs increased from 112,000 tonnes in 1978 to more than 2.23 million tonnes in 2005 (FBMA, 2006) (Figure 1), currently averaging nearly 1200 kg/ha. Even so, the reservoir fisheries sector is considered to have still more potential for further development. Reservoir areas suitable for fish production represent about 30.1% of the total freshwater area in China, but the fish production from reservoirs represents only 11.7% of the total freshwater production (FBMA, 2006) (Figure 2). Therefore, reservoir fisheries could play a more important role in the future.

Establishment of stocking and management systems

Bighead carp and silver carp are two of the four major Chinese carps in China traditionally cultured for many years in ponds and lakes. They have several favourable biological characteristics such as rapid growth rate, easy capture, strong disease resistance and easy availability of fry and fingerlings. They are used as the dominant stocked species in reservoirs for intensive, and semi-intensive aquaculture. They account for up to 70% of the total catch in almost all reservoirs. In most reservoirs, the ratio of bighead carp stocked to silver carp is 2:1 or 3:1. Nevertheless, in reservoirs where fertiliser is applied, the ratio of bighead carp is about half that of silver carp. For example, in Qingyunhe Reservoir in Liaoning Province (92 ha) which is fertilised with the waste water from a chemical fertiliser factory, stocking of silver carp results in good economic returns.

Figure 1. Reservoir fish production and surface area from 1978 to 2005.

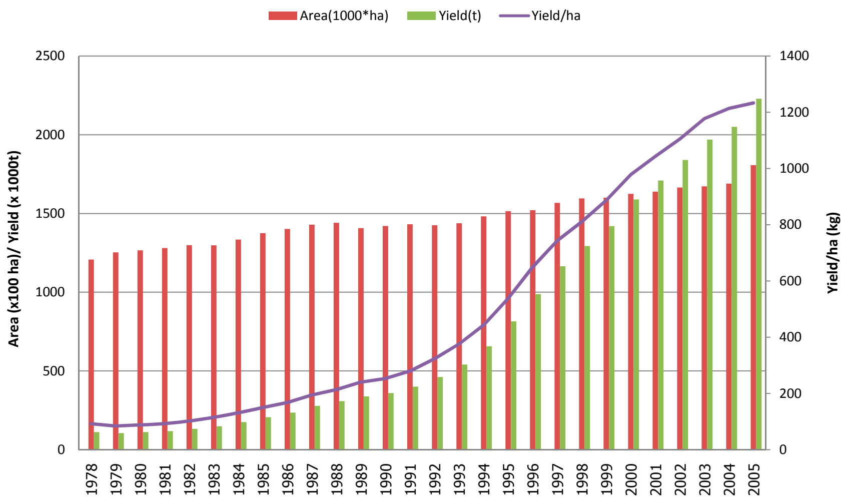
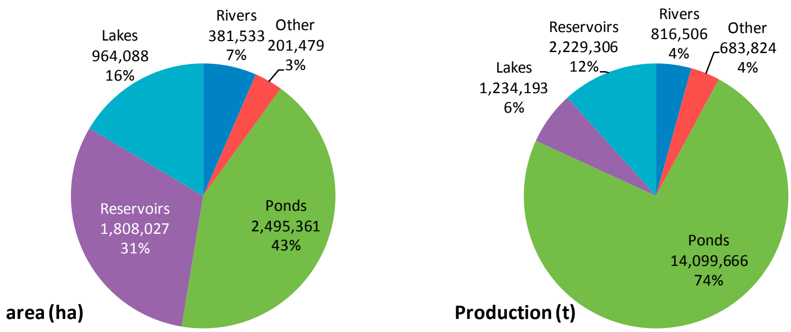


Figure 2. Percentages of surface area (ha) of different types of water bodies and fish production thereof (in tonnes), currently.



Stocking large sized fingerlings in reservoirs is also practised to ensure fast growth, high recapture rate and high fish production. Generally, silver carp and bighead carp of over 15 cm in length are stocked. The stocking density is calculated as $d=f/ws$, where d is the annual stocking density (fish/ha), f is the annual fish yield (kg/ha), w is average harvesting size (kg) and s (%) is the recapture rate (Li and Xu, 1995).

Besides bighead carp and silver carp, small proportions of common carp (*Cyprinus carpio*), *Xenocypris*, mud carp (*Cirrhina molitorella*), Nile tilapia (*Oreochromis niloticus*), grass carp (*Ctenopharyngodon idella*), Chinese bream and mitten crab are also stocked in some reservoirs as supplementary species.

New icefish (*Neosalanx taihuensis*) and large icefish (*Protosalanx hyaloeraniius*) have also been stocked in recent years. Icefish is small sized but high priced fish. Its lifespan is only about one year. They reproduce naturally in reservoirs and are easily captured. The total production of this small-sized new icefish is very high. New icefish is translocated into reservoirs in Southern and Central China, but large icefish is introduced into reservoirs in Northern China (Liu *et al*., 2001). A few years after introduction, icefish is able to support commercial production. Many reservoirs benefit from the introduction of icefish, especially those in Yunnan, Hubei, Jiangsu, Shongdong and Inner Mongolia.

Reservoir fisheries are under the jurisdiction of the Chinese Ministry of Water Resources. However, all other fisheries including marine fisheries and fisheries from ponds, lakes, rivers and rice fields are under the administration of the Chinese Ministry of Agriculture (Wu, 1998). In most medium and large sized reservoirs, an administration agency is set up to manage the stocking, capture, sale and water resources. Usually, a hatchery is built below the dam in medium and large reservoirs to supply fingerlings for stocking. For new reservoirs, building a fish hatchery is required by law.

Fish productivity assessment in reservoirs

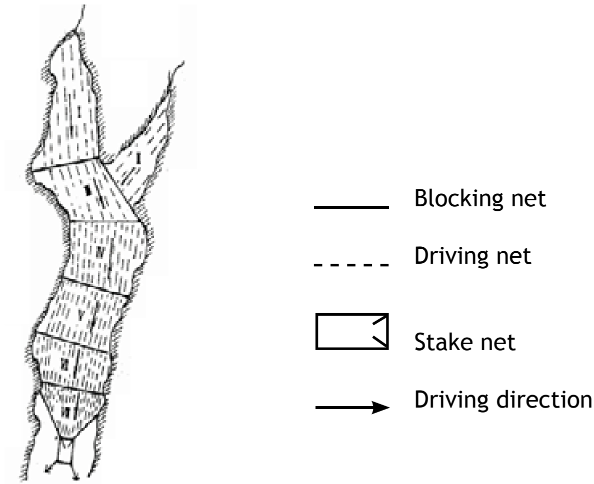
Almost country-wide survey of reservoir limnology was made in the 1980s. Different types of reservoirs were identified based on morphological characteristics, principal nutrient concentrations and biomass of aquatic organisms (Dai and Xu, 1996). The methodology was developed to predict silver carp and bighead carp production from phytoplankton primary production. Xiong (1996), based on the analysis of 15 factors affecting fish yield in 32 reservoirs, has shown that mean depth, catchment area, water temperature, precipitation, dissolved oxygen content, total phosphorus, phytoplankton biomass and the number of stocked fingerlings are the major factors influencing fish yield. These factors can be used as an ecological index for estimating fish yields in reservoirs.

Improvement of capture techniques

Efficient fish capture in large and medium sized reservoirs was problematic due to greater water depth. As such, a combination of capture techniques called 'United Fishing Method' is used to capture fishes, which uses driving nets, bar nets, gill nets and stake nets. The blocking and driving operations are also conducted simultaneously with capture so that all fish are forced to aggregate in a certain location which would facilitate capture (Figure 3). The United Fishing Method is a large-scale operation covering the whole reservoir. This method of fishing has met with widespread acceptance in Chinese reservoirs. It was practiced in Fuqiaohe Reservoir, Hubei Province and resulted in a catch of 270t of fish in a single haul in 1980 (Liu and Huang, 1998). The united fishing method can be used for a fishing area from a hundred to thousands of hectares. The method mainly captures silver carp and bighead carp, but also captures some grass carp, bream and other fish species. Moreover, some bottom fishes, such as common carp and Crucian carp, can also be harvested using this method. Improvement of fish escape preventing techniques.

Fish escapes from reservoir spillway and turbines are a common problem, causing great losses for fish farmers. A new electric facility is developed to prevent fish escaping from reservoirs. This facility can both drive fish away from turbine and spillway area and block the fish from escaping.

Figure 3. Sketch map of the united fishing method in a reservoir (Modified from Li and Xu, 1995)



Standardisation and extension of fisheries techniques

In order to standardise the fisheries practices in reservoirs, a set of standards or regulations have been established, as listed below.

- Standard for the Investigation of Reservoir Fishery Resources (1996).
- Standard for the Fishery Trophic Classification (1999).
- Standard for a Complete Set of Fishery Installations of Reservoirs (1994).
- Design Criterion of Reservoir Management (1996).
- Fish Culture Technical Regulations of Reservoir Interception Arm (1996).
- Technical Regulations for the Transplantation and Propagation of Large Icefish in Reservoirs (1998).
- Technical Requirements for Monitoring of Total Amount of Pollutants in Waste Water (2002).
- Technical Regulations for the Artificial Propagation of Chinese Sucker (1998).
- Technical Regulations for the Artificial Propagation of Chinese Sturgeon (1998).
- Technical Regulations for Reservoir Fish Farming by Fertilisation (1996).

A full extension system of reservoir fisheries techniques has been established including research, training and production. There are fisheries research institutes from central government level to provincial level. In the central government level, the Chinese Academy of Fisheries Sciences attached to the Ministry of Agriculture, the Institute of Hydrobiology attached to the Chinese Academy of Sciences, National Engineering Centre for Freshwater Fisheries attached to the Ministry of Science and Technology, and the Institute of Hydro-ecology (originally Reservoir Fisheries Research Institute) attached to the Ministry of Water Resources are relevant to reservoir fisheries research. There are more than 15 fisheries journals published in China, including the Journal of Reservoir Fisheries.

Challenges to development of reservoir fisheries

Even though reservoir fisheries have achieved a significant success, it also encountered challenges, some of which being associated with the liberalisation of the economy and the increased living standards of people. These challenges include, the demand for higher quality food fish, and the resultant decrease in demand and hence the price of species used traditionally in the culture based fisheries, the conflict between aquaculture and the environmental protection, need to rationalise the stocking practices, prevalence of sudden-and violent disease problems and an imbalance of the fisheries development in different regions, and the low economic returns from cage culture.

Simplification of species cultured in reservoirs

Species composition of fishes used for reservoir stocking in China is dominated by silver carp and bighead carp. However, there are disadvantages associated with these species although they contribute significantly to Chinese reservoir fisheries. They have low market value. Also high stocking rate is necessary to gain good economic returns, which increases investment and also pressure of fisheries on water environments (Liu *et al*., 1998). Since they are planktivores, they are restricted to the upper part of water column and as a result, the middle and lower parts of the water column are virtually unutilised. Silver and bighead carps have strict requirements for natural reproduction. Their spawning should be stimulated by proper water flow and water temperature. Their eggs are drifting so that hatching out eggs takes place after drifting forover 100 km in the water flow in the riverine habitats (Yi *et al*., 1988). As reservoirs do not possess such conditions, even though these carps can occasionally spawn in the upper stream of some large reservoirs, the eggs will sink to the bottom and die (Wei, 1985). Therefore, a significant amount of manpower and funds need to be spent to stock these fingerlings every year. Insufficiency of stocking in some reservoirs due to financial constraints results in the under utilisation of biological productivity that could be harnessed for human benefit. In order to achieve high fish yields, fish farmers often fertilise reservoirs (Deng, 1992), which deteriorates water quality and affects other functions of reservoirs.

Generally speaking, over-stocking of silver carp and bighead carp conflicts with the protection of water quality and economic efficiency.

Irrational structure of stocked fish populations

In China, piscivorous fishes are not considered as stocking material in reservoirs. They have been thought to be harmful to stocked fingerlings and should be captured thoroughly (Chen *et al*., 1978). As a result, the reservoir ecosystems have become suitable for the growth and reproduction of trash fish. In reservoirs of the middle and lower reaches of the Yangtze River, the number of trash fish species amounts to more than half of the total fish species (Liu and Huang, 1998). The food conversion efficiency of trash fish is generally very low. The presence of trash fish in high abundance also decreases the ecological efficiency of reservoirs. On the other hand, the trash fish compete for food with stocked fish, which also conflicts with fisheries production. Furthermore, the trash fish is almost a waste resource in reservoirs because of the lack of effective capture methods and low market price (Liu and Hu, 2000).

Prevalence of the sudden and violent fish disease

For a long time, reservoirs have been famous for good water quality and the prevalence of fish diseases has not been a problem. In the recent years however, the sudden—and-violent fish diseases have been very common in Chinese reservoirs as a result of intensive culture such as cage culture, cove culture, and applications of fertilisers, which cause big losses to fish farmers (Gao *et al*., 1997). It is predicted that with the development of culture scale and culture intensity, this disease will be even more harmful.

Imbalance of the development

The development processes of reservoir fisheries in China are very imbalanced in different areas. The average annual reservoir fish yield in China is about 500 kg/ha. However, in the developed areas such as in Central China, Eastern China, Southern China, the annual fish yield in some reservoirs is over 3000 kg/ha. On the other hand, in most of the reservoirs of South-west China and North-western China, reservoir fisheries are under-developed and the average annual fish yield is less than 150 kg/ha. Due to warm climate and the presence of nutrient rich water and fish resources in South-west China, there is a great potential for the development of reservoir fisheries in these areas.

Low economic returns from cage culture

Cage culture is suitable for large water bodies, which involves high investment and high economic returns. Cages were first used in Chinese reservoirs in the 1970s to rear large-sized fingerlings for reservoir stocking, since many reservoirs had insufficient pond capacity for fingerling rearing (Liu and He, 1992). The species cultured in this period were silver carp and bighead carp. Fish farmers and reservoir administration units benefited from this new culture method, since the two species cultured fed on naturally occurring plankton and no formulated feeds were used. In the recent years, with the development of market economy and the higher demand for high quality fish, cage culture with formulated feed or live organisms has become popular in reservoirs all over China. However, cage culture did not produce good economic returns for fish farmers mainly due to the following problems.

- High feed cost.
- Irrational cage structure and location of cages in the water body.
- Low price for cage cultured species.

High feed costs

The ratio of feed price to product price is over 70% for cage culture of common carp and grass carp, which discourages fish farmers to engage in cage culture. One of the reasons for the high fish feed cost is that almost all fish meals in China are imported. Furthermore, several other reasons exist bringing about wastage of feed. As the determination of ration for cage cultured fish is based solely on observations, feeding regimes and quantities bring about waste of feed. The irrational feeding methods involving the feeding frequency of 2-3 times per day within a short period also lead to waste of feed. Poor feed formulation techniques are also responsible for feed waste. Feeds made in China are normally not bond well and powders represent a certain fraction in feed. These feeds are easily dissolved in water and also blown away by wind, which also increases feed conversion rate (Liu *et al.*, 1997). Insufficient knowledge about fish nutrition is also responsible for producing nutritionally unbalanced feeds. The feed conversion rate for cage culture is about 1 in the developed countries (Beveridge, 1987), but it is about 1.5 or more in China.

Irrational structure and location of cages in the water body

The cages of small-volume with the area of 10-30 m^2 are popular in Chinese reservoirs. As these cages cannot withstand strong wave action, they are generally installed in area less affected by wind, such as reservoir coves. These locations have lower water exchange rate and lower dissolved oxygen concentration so that the stocking density that can be used is limited resulting in partial utilisation of the fisheries potential. Furthermore, the loadings from cage culture are easily accumulated in such places which result in the eutrophication and disease spread. In Heilongtan Reservoir, a large reservoir with an area for aquaculture of 1693 ha in Sichuan Province, dissolved oxygen levels often decreased due to cage culture.

Low price for cage cultured species

The common species cultured in cages include common carp, grass carp and tilapias. Although they produce high yields, the economic returns are low due to low price. This leads to less enthusiasm of fish farmers in cage culture.

Conflicts between reservoir fisheries and environmental protection

With the increasing deficiency of water resources and further deterioration of water quality, the conflict of reservoir fisheries with environmental protection becomes more serious (Liu *et al.*, 1997). People are concerned about water pollution caused by cage culture in reservoirs. In Gaobazhou Reservoir with a surface area of about 500 ha in Hubei Province, the water quality was very good (type II water by Chinese standards) ten years ago. However, with proliferation of the large scale cage culture of the American channel catfish, the water quality has highly deteriorated (type IV water). The government and the environmentalists are much concerned about cage culture in reservoirs. For example, in the Three Gorges Reservoir, the biggest reservoir of the world, cage culture is completely prohibited.

Future strategies

For sustainable development of reservoir fisheries in China, some strategies are needed to be considered. Perhaps the renewal of stocked species is an effective strategy instead of the traditionally stocked planktivorous fish species, silver carp and bighead carp, which have low market demand. Research directed towards selection of high valued planktivorous fish species which can partially replace the traditionally stocked species should be one of the research priorities. In the early 1990s, the icefish *N. taihuensis*, a planktivorous fish mainly feeding on zooplankton, was stocked into some reservoirs in Central and Southwestern China. Many reservoirs are benefiting from this new species. For example, Zhanghe Reservoir, an oligotrophic reservoir of 7000 ha in Hubei Province without any other stocked species, was stocked with 200,000 fertilised new icefish eggs in 1992 (Liu *et al.*, 2000). From 1996 to 1998, the annual yield of the new icefish was over 100 tons with a market value of more than 1.5 million Chinese yuan (6.8 Yuan=1 US$). This amount is equivalent to the market value of 300 tonnes of all the fish products in Fuqiaohe Reservoir, an eutrophic reservoir of 1,500 ha in Hubei Province. The later reservoir is known for the early development of many reservoir fisheries techniques and also for the research base of the Institute of Reservoir Fisheries, the Chinese Ministry of Water Resources and the Chinese Academy of Sciences (Liu and Huang, 1998). In Geheyan Reservoir, an oligotrophic new reservoir of about 7,000 ha in Hubei Province, the new icefish was stocked in 1996, which produced more than 300 tonnes in 1998. The new icefish can spawn naturally in reservoirs so that regular stocking is not required. They can be easily harvested by trawl nets so that large-scale capture with the United Fishing Method (Li and Xu, 1995) is not necessary. Furthermore, fishers in reservoirs with the new icefish are also benefited by selling fertilised eggs. In 1997, fishers in Zhanghe Reservoir sold 54.45 million icefish eggs and earned about 1 million Chinese yuan.

The American paddlefish *Polyodon spathula*, a planktivorous fish mainly feeding on zooplankton, perhaps is another alternative for partial replacement of bighead carp. This species is known for its high quality meat and high priced eggs in North America (Liu and Yu, 1990). Since the early 1990s, China has been introducing the American paddlefish every year from the United States. It showed high growth rates both in the open water and cages. This fish can be easily caught with gill nets and it may spawn and hatch naturally in some large reservoirs (Liu and Hu, 2000). Also, presently the artificial propagation of the American paddlefish is successful in China so that import of fish from the United States is no longer a necessity. The only concern is that the American paddlefish may escape from stocked reservoirs into the Yangtze River and cross-breed with the endangered Chinese paddlefish *Psephurus gladius*.

Silver carp and bighead carp only use the trophic spatial niches in the top layer in reservoirs. As such, there appears to be a provision to stock demersal fishes into reservoirs in order to enable full use of the food resources and space in a reservoir ecosystem. The common carp *C. carpio*, a benthos predator, is commonly found in Chinese lakes, but large populations of the fish are rarely found in Chinese reservoirs because of the lack of aquatic plants as their spawning substrates. Most of sturgeons live in the bottom layer of water bodies and feed on benthos. Reservoirs provide good water quality and rich benthos for their growth. Sturgeons generally grow faster in reservoirs than in rivers and can be easily caught by gillnets (Wei, 1985). The rivers in the upper parts of large-sized reservoirs may be suitable for the reproduction of sturgeons (Wei, 1985). Stocking sturgeons into reservoirs perhaps is a rational choice for making better use of reservoir resources and improving economic situations (Liu and Hu, 2000).

The organic detritus is an important food resource of fishes (Chang, 1995). In Heilongtan Reservoir, a eutrophic reservoir of 1693 ha in Sichuan Province, the annual fish production potential based on organic detritus was estimated at 473 tonnes (Chang, 1995; Hu *et al.*, 1998). However, large fish populations that feed on organic detritus are rarely found in reservoirs. *Xenocypris davidi* and *X. microlepis* feed mainly on organic detritus and are commonly found in the Yangtze River and the associated water bodies (IHHP, 1976). Stocking of these two species into reservoirs or strengthening the protection of their reproductive populations may increase fish production and economic returns significantly.

Piscivorous fish have a very important role in aquatic ecosystems. Some large-sized pelagic piscivorous fish like *Elopichthys bambusa* harm the stocked fingerlings of silver carp and bighead carp. As such, population sizes of this piscivorous species needs to be strictly controlled. However, some small- or medium-sized piscivorous fishes like mandarin fish *Siniperca chuatsi*, Chinese snakehead *Channa argus* and large icefish *P. hyalocranius* may not harm stocked fingerlings. Instead, they can convert the low valued trash fish into high valued fishery products. Furthermore, piscivorous fishes command a high market price, and a lower stocking rate may produce a higher economic return, decreasing pressure of fisheries (Liu *et al.*, 1998). Studies in North America and Europe showed that stocking of piscivorous fishes into lakes could improve water quality by trophic cascading effects (Carpenter and Kitchell, 1988; McQueen, 1990). Determination of appropriate stocking number of piscivorous fish in a water body is important. Bioenergetics models can be used to predict the growth and food consumption of fish (Hewett and Johnson, 1992; Brandt and Hartman, 1993). Studies of the productivity of trash fish in a reservoir and the bioenergetics model of the piscivorous fish will help determining the appropriate stocking rates of piscivorous fish based on predator-prey relationships.

Catching demersal fish efficiently in reservoirs is somewhat problematic. Hence, studies on fishing gear technology for capture of demersal fish are necessary.

Cage culture practices also need to adopt changes, such as in cage structure and location of cages in a water body, which will increase the economic efficiency, decrease pollution, and control incidence of diseases (Peng *et al.*, 2004).

A strategy to develop intensive culture of high-valued fish through the use of the discharged water below reservoir dams needs to be explored. In Miyun Reservoir, Beijing, several different cold water fish species such as salmonids and sturgeons are cultured, resulting in good economic returns. Through these culture practices, water pollution can be efficiently controlled.

Carrying capacity of reservoirs for aquaculture is a main concern in recent years because of the deteriorated water quality in reservoirs. Standards for determining the carrying capacity of reservoirs with different functions should be established. A standard method for assessing the carrying capacity of water body for cage culture has been developed (Peng *et al.*, 2004), but needs to be validated. Carrying capacity of reservoirs for other aquaculture practices should also be developed.

Acknowledgements

The present study is under the auspices of the National Science Technology Program of China (2006BAD03B02, 2007BAD37B03) and National Natural Science Foundation of China (30771642).

References

FBMA, 2006. *China Fisheries Yearbook*. Agricultural Press of China, Beijing (in Chinese).

Beveridge M.C.M., 1987. *Cage Aquaculture*. Fish News Books, Surrey.

Brandt, S.B., Hartman, K.J., 1993. Innovative approaches with bioenergetics models: future applications to fish ecology and management. *Transactions of the American Fisheries Society*, 122: 731-735.

Chang, X., 1995. Preliminary studies on particulate organic detritus in Heilongtan Reservoir. *Reservoir Fisheries*, (3): 24-27 (in Chinese).

Chen J., Lin Y., Wu Z., 1978. Regularities of succession of predatory fish population in reservoirs of the middle and lower Chang Jiang Valley, with a discussion on the methods of population control. *Oceanogia et Limnologia Sinica*, 9: 49-58 (in Chinese).

Carpenter, S.R., Kitchell, J.F., 1988. Consumer control of lake productivity. *BioScience*, 38: 764-769.

Dai, Z., Xu, X., 1996. An approach to eutrophication classification standard in reservoirs. *Reservoir Fisheries*, 2: 3-6 (in Chinese).

Deng, X., 1992. Fish culture with fertilisers. *Hunan Science Technology Press* (in Chinese).

Gao, H., Chen, C., Lin, Y., 1997. Epidemiological investigation of outbreak disease of fishes and its prevention treatment in some reservoirs. *Reservoir Fisheries*, 1: 8-10 (in Chinese).

Hewett, S.W., Johnson, B.L., 1992. *Fish Bioenergetics Model* 2. University of Wisconsin, Sea Grant Institute, WIS-SG-92-250, Madison.

Hu, C., Lin, T., Wu, H., Gao, H., Chang, X., 1998. Studies on comprehensive fishery exploitation of Heilongtan Reservoir in Sichuan Province, China. *International Reviews in Hydrobiology*, 83(special issue): 535-538.

IHHP (Institute of Hydrobiology of Hubei Province), 1976. *Fishes of the Yangtze River.* Science Press, Beijing (in Chinese).

Li, S., Xu, S., 1995. *Culture and capture of fish in Chinese reservoirs*. International Development Research Centre, Southbound Sdn. Bhd., Penang, Malaysia.

Lin, W., 1990. The organic detritus and its function in the ecological ecosystem of Lake Donghu. In: Liu, J. (ed.). *The Ecological Studies of Lake Donghu*, Vol. 1, pp. 242-291.

Liu, J., 1996. Effects of cage culture with feed on the environment. *Reservoir Fisheries*, 1: 32-34 (in Chinese).

Liu, J., Cui, Y., Liu, J., 1997. Advances in studies on the effect of cage culture on the environment. *Acta Hydrobiologica Sinica*, 21(2): 174-184 (in Chinese).

Liu, J., He, B., 1992. *Cultivation of the Chinese freshwater fishes* (3rd edition). Science Press, Beijing, 750 pp (in Chinese).

Liu, J., Hu, C., 2000. Sturgeons and their status and function in reservoir fisheries, *Reservoir Fisheries*, 20: 1-4.

Liu, J., Huang, Y., 1998. Fisheries and fish culture practices in Fuqiaohe Reservoir, China. *International Reviews in Hydrobiology*, 83 (special issue): 569-576.

Liu, J., Peng, J., Yu, F., Jiang, J., Yao, X., Yi, Y., 2001. Estimation of the new icefish *Neosalanx taihuensis* yield in Zhanghe Reservoir, China. In: De Silva, S.S. (ed.). *Reservoir Culture-based Fisheries: Biology and Management, Proceedings of an International Workshop held in Bangkok, Thailand from 15th-18th February 2000.* Australian Centre for International Agricultural Research, Canberra.

Liu, J., Yu, Z., 1990. The paddlefish (*Polyodon spathula*) and its fisheries in the USA. *Acta Hydrobiologica Sinica*, 14(1): 75-83 (in Chinese).

Liu, J., Cui, Y., Liu, J., 1998. Food consumption and growth of two piscivorous fishes, the mandarin fish and the Chinese snakehead. *Journal of Fish Biology*, 53: 1071-1083.

Liu, J., Yu, Z., Dai, Z., 1992. Present status and prospects for reservoir fisheries in China. In: *Reservoir Fisheries of Asia. Proceedings of the 2nd Asian Reservoir Fisheries Workshop held in Hangzhou, People's Republic of China, 15-19 October 1990.* Interntional Development Research Center, Ontario.

McQueen, D.J., 1990. Manipulating lake community structure: where do we go from here. *Freshwater Biology*, 23: 613-620.

Peng, J., Liu, J.,Xiong, B., 2004. Carrying capacity of water body for cage culture. *Acta Ecologica*, 1: 28-34.

Wei, Q., 1985. An approach to developing sturgeon fishery in China. *J. Huazhong Agricultural College*, 4(2): 23-31 (in Chinese).

Wu, J., 1998. Reservoir fisheries in China. *International Reviews in Hydrobiology*, 83 (special issue): 611-618.

Xiong, B., 1996. A principal component analysis of ecological factors affecting fish yield in reservoirs. *Reservoir Fisheries*, 1996: 3-6 (in Chinese).

Yi, B., Yu, Z., Liang, C., 1988. *The Gezhouba Water Projects and the Four Domestic Carps in the Yangtze River.* Wuhan Science and Technology Press of Hubei Province (in Chinese).

Status of Reservoir Fisheries in India

K.K. Vass[1] and V.V. Sugunan[2]*

1. Central Inland Fisheries Research Institute, Barrackpore - Kolkatta, India.
2. Indian Council of Agricultural Research, New Delhi, India.

Introduction

Reservoirs contribute considerably to the inland fish production of India which has been estimated at 93,000 tonnes (Anon, 2006) In spite of this fact, reservoir fish production has been treated as a by-product, giving it less importance as a fish production system. For this reason, reservoir fisheries have not made significant progress in the country and do not contribute to inland fish production of the country to the extent they could. However, subsequently, the managers of a majority of the water and power projects in the country have realised that fisheries need to be given its due importance in overall reservoir management. Unlike rivers, which are under increasing threat of environmental degradation, reservoirs in India offer ample scope for fish yield optimisation through effective management (Vass, 2007). The sheer magnitude of the resource makes it possible to enable substantial increase in production by even a modest improvement in yield. Further, the importance of reservoirs derives mainly from advantages from environmental and social perspectives. The benefit of increased yield and income generated of fishing communities of reservoirs is more equitably distributed. There is also a need to dovetail the twin objectives of yield optimisation and environmental conservation.

Reservoirs

Government of India defines reservoirs as man-made impoundments created by obstructing surface flow, by erecting a dam of any description on a river, stream or any water course. However, water bodies less than 100 ha in area have been excluded from this definition. The Ministry of Agriculture, Government of India has classified reservoirs as small (<1000 ha), medium (1,000 to 5,000 ha) and large (>5000 ha) for the purpose of fisheries management, although different states have varied classifications. The estimated cumulative areas are 1,485,557 ha, 507,298 ha and 1,160,511 ha of small, medium and large reservoirs, respectively (Sugunan, 1995).

India has 19,370 reservoirs spread over 15 states with an estimated 3.15 million ha surface area at full capacity, and this is expected to increase due to execution of various water projects in the country. Tamil Nadu state has the highest reservoir area of small reservoirs, investigated by Sreenivasan (1989), followed by the states of Karnataka and Andhra Pradesh. The state of Madhya Pradesh has the highest total area of small reservoirs as well, whilst Andhra Pradesh, Gujarat and Rajasthan also have a higher area of medium reservoirs.

Karnataka has the most large reservoirs (twelve), but the total acreage is less when compared to the cumulative extent of seven reservoirs in Andhra Pradesh.

Morphometric and hydrological features

In reservoir ecosystems, climatic and edaphic factors are responsible for energy fixation and nutrient dynamics, thus considered to be of first order importance followed by morphometric factors (basically area, mean depth, irregularity of shoreline) having significant bearing on productivity.

Mean depth (volume/area) in reservoirs is considered to be one of the most important morphometric parameters indicative of the extent of the euphotic - littoral zone (Rawson 1952, 1955). A relationship between fish yield and MEI has been worked out in some African reservoirs by Henderson and Welcome (1974).

Henderson et. el, 1973) For a few Indian reservoirs MEI was also worked out by Ramakrishna (1990) but no statistical relationship was established. Some of the deeper reservoirs of India with mean depth of 21.1 m and 18.0 m have poor productivity. However, other deep reservoirs such as Bargi (14 m) in Madhya Pradesh, Chamera (43.5 m) and Govindsagar (55.0 m) in Himachal Pradesh, Rihand (22.8 ha) in Uttar Pradesh, and Badua (14.5 ha) in Bihar are productive due to other favourable factors. Thus, it appears that in Indian reservoirs, depth is not always a constraint to productivity. Fortunately, most of the small and medium sized reservoirs are of low mean depth (4-7 m) and show high fisheries potential.

Table 1. State-wise area of small, medium and large reservoirs (ha).

State	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	39,161	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
North eastern state	2,239	5,835	-	8,074
Total	**1,485,557**	**507,298**	**1,160,511**	**3,153,366**

Table 2. Average range of some morphometric and hydrological features of some reservoirs in different states.

State	Area (ha)	Mean depth (m)	Elevation (m msl)	Catchment area (km^2)
Jammu & Kashmir	NA	25	NA	NA
Himachal Pradesh	900-15,000	20-55	440-899.2	4,725-56,980
Punjab	46-280	4-10	NA	6.1-56.1
Haryana	NA	3.4-5	NA	11.4-11.9
Rajasthan	165-1,554	1.7-7.7	NA	35-27,840
Uttar Pradesh	17.5-30,149	3-22.8	119-268	32.4-13,344
Madhya Pradesh	77-66,000	3.4-14	348.7-488.3	8.3-23,025
Bihar & Jharkhand	21-3,733	5.2-14.6	NA	29-6,120
West Bengal	NA	3.2-11	NA	NA

The Indus basin catchment is comparatively less fertile than that of the Ganges basin where gangetic alluvial soil boosts productivity of the reservoirs and of the basin as a whole (CIFRI, 1986). The Gangetic basin is mostly covered with intensely cultivated agricultural lands with a moderate to high rainfall (250-4000 mm). In contrast, the upper Indus flows through glacial terrains before emerging onto the plains in the lower reaches, also receiving comparatively less rainfall (100 mm) in the lower plains than in the upper plains (750 mm). The predominant soil formation is an illitic clay dominated alluvium zone with high potassium content and moderate nitrogen and phosphorus content in the Gangetic basin while the Indus basin soils are poor nutrients mainly in the upper reaches, with low to moderate nitrogen and phosphorus content in Punjab, Haryana and Himachal Pradesh (CIFRI, 2006). The fertility status is augmented due to the application of inorganic fertiliser in the agricultural lands. Temperature in the upper regions is 2-16°C compared to the lower regions 24-35°C.

De Silva (1988) suggested that in shallow reservoirs, the reservoir bed may serve as a source of autochthonous nutrient loading. However, in Indian reservoirs it has been noticed that the catchment determines the water quality to a larger extent than the basin soil (Natarajan, 1976, 1977, 1979; Jhingran, 1986). The extent of catchment has a positive impact on the reservoir productivity, provided the catchment is moderately fertile. The catchment (C) to reservoir area (A, at FRL) is considered to be an index of allochthonous input (De Silva and Amarasinghe, 1989), varied in a narrow range in the case of small and medium reservoirs in India *viz*., Dahod (6), Sampna (17), Sarni (35), Kolar (21), Kerwa (13) in Madhya Pradesh, Baghla (13), Bachra (17), Nanaksagar (1.3), Gularia (12.6) in Uttar Pradesh, Getalsud (20), Konar (38), Badua (3) in Bihar, and even in case of the large reservoirs such as Halali (9), Barna (15), Bargi (53), Tilaiya (16) and Gandhi Sagar (34), the catchment : area ratio is lower.

Flushing rate (inflow/storage capacity) is important since it regulates both the degree and regime of nutrient loading (Vollenweider, 1969). The flushing rate is very high in case of reservoirs in Himachal Pradesh, Bihar, Jharkhand and West Bengal and moderate in Madhya Pradesh, while it is low in Rajasthan. In the majority of Indian reservoirs drastic fluctuations in water level have been observed to impact plankton, benthos and periphyton pulses that coincide with the period of least water level and that all the communities are at a low ebb during the months of maximum water level and water discharge (Unni, 1993).

Physico-chemical features of reservoirs

Coarse and fine sand predominate the basin soil in the majority of the reservoirs of Rajasthan, Haryana, Uttar Pradesh, and Punjab followed by Madhya Pradesh, Himachal Pradesh, Jharkhand and West Bengal. Silt deposition has been observed mainly along the river course and thus in majority of the reservoirs in Gangetic plains the sediment is mostly sandy-clay type.

Chemical characteristics

Soil reaction

Soil is mostly neutral to moderately alkaline in reservoirs reflecting a moderate productive trend. Moderately acidic basin soils were observed in some reservoirs in Bihar and Jharkhand due to the forest-covered catchment. The release of phosphorus is basically dependent on soil pH. Bottom sediment containing a high level of organic matter with slow decomposition rate develops acidity due to humic and short chain fatty acids, leading to less productivity (Shrivastav and Das, 2003). The favourable pH range for biological productivity is 6.5 - 7.5.

Nutrients

Available nitrogen

Nitrogen is the basic and primary constituent of protein and is basically present in soil in organic form getting mineralised gradually to ammonium (NH_4^+) and nitrate (NO_3^-) forms thus making their availability to fish food organisms.

Table 3. Basic sediment characters of some reservoirs (average values of different case studies.

State	pH	Organic content (%)	Available N (mg/100 g)	Available P (mg/100 g)
Himachal Pradesh	6.6-6.7	1.1-1.5	71-81	5.6-5.8
Punjab	6.5-7.5	0.25-1.20	45-74	4.8-8.0
Haryana	7.0-7.5	0.5-0.6	32-38	5.8-6.2
Rajasthan	6.8-7.5	0.28-1.20	7-50	0.1-4.0
Uttar Pradesh	6.5-7.6	0.28-3.5	22-60	0.8-2.6
Madhya Pradesh	6.1-8.0	0.4-1.5	25-68	0.7-2.8
Bihar & Jharkhand	5.4-6.5	0.3-0.9	24-47	1.2-8.0
West Bengal	6.4-7.8	0.3-0.8	20-55	0.4-2.4

Reservoirs in Punjab, Himachal Pradesh, Madhya Pradesh, Uttar Pradesh and West Bengal having moderate available nitrogen content but are of moderate to high productivity.

Available phosphorus

Soil available phosphorus (mg/100g soil) should be in the range of 4.7 to 6.2 for high biological productivity but it is of low profile in Indian reservoirs. Its range (mg/100g) in reservoirs, especially in Punjab, Himachal Pradesh, Jammu and Kashmir, Haryana, was of very high order while it was low in other reservoirs.

Organic matter and carbon : nitrogen ratio

As per available data comparatively low to moderate organic carbon (%) content is recorded in most of the Indian reservoirs. Generally bottom sediment with 1.5-2.5% organic carbon is considered to be productive.

Nitrogen mineralisation or immobilisation is solely governed by the carbon : nitrogen (C:N) ratio - the higher the C : N ratio (>20) higher the immobilisation of inorganic nitrogen as compared to lower C : N ratio (<10) resulting in mineralisation of organic nitrogen in soil, rendering nitrogen to be added to the water column. Some of the reservoirs in Uttar Pradesh, Bihar and Madhya Pradesh have shown higher C : N ratio due to acidic nature of soil.

Physical characteristics of water

Normally the transparency of water decreases during the monsoon due to inflow being loaded with dissolved and suspended organic and inorganic particles, subsequently stabilising in the post-monsoon period. Water transparency has a significant role in light attenuation with depth, affecting productivity. Reservoirs with rocky and gravel catchment such as those in Jammu and Kashmir, Himachal Pradesh and Jharkhand have deeper euphotic zones of more than 2 m (Table 4). In these reservoirs the temporal variation in transparency is very wide unlike Madhya Pradesh reservoirs (Unni, 1985). As the reduced transparency in these reservoirs is due to suspended inorganic particles and phytoplankton production is much less, unlike reservoirs with high phytoplankton growth limiting light penetration.

Thermal stratification

In tropical Indian reservoirs, thermal stratification is not stable and prolonged. The degree of stratification is low in comparison to temperate reservoirs. Even though the period of thermal stratification is short, it has a significant influence on biological productivity. Stable thermal stratification has not been reported in reservoirs of the western, eastern or central parts of India. In a majority of reservoirs, on average, the temperature declined by 1-2°C from surface to bottom. Even the deeper reservoirs such as Bargi, with a maximum depth of 59 m, do not show stable thermal stratification.

In some north Indian reservoirs, thermal stratification occurs during summer with three distinct phases. e.g., In Getalsud reservoir in Bihar (mean depth 4.52 m and area 3,400 ha at FRL) the epilimnion extending up to 6 m, with a stable thermocline / metalimnion in a range between 7 and 12 m and hypolimnion below 12 m (Pal, 1979). The temperature drop in the thermocline region was from 25.3°C at 7m to 20.8°C at 11m. Similar patterns of thermal stratification have also been reported in other north Indian reservoirs such as Konar (Sarakar, 1979) where the metalimnion occurred between 3 to 9 m depth and temperature dropped from 0.7 to 1.1°C per metre. In Rihand (Desai and Singh, 1979), a well defined metalimnion between 4 to 13 m with a fall of temperature between surface and bottom at 10°C, 8.5°C and 9.5°C in May 1975, 1976 and 1977, respectively has been reported. In Govindsagar reservoir, a very strong and well defined thermocline was observed (Sarkar *et al.*, 1977). Thermal stratification with a fall in metalimnion temperature of less than 1°C has been observed in many tropical lakes (Le-Cren *et al*., 1980). Similar trends are evident in the upper peninsular reservoirs comprising south Bihar, Madhya Pradesh and Gujarat which undergo transient phases of thermal stratification during summer. Apart from the year-round high water temperature and continuous draw down from deeper layers, the wind and wave mediated turbulence facilitate mixing of the water column.

Chemical features of water

Dissolved oxygen

Generally, dissolved oxygen (DO) are higher during the pre- and post-monsoon seasons than in the monsoon periods in Indian reservoirs due to the downpour. DO is greater during March-April in some tropical and peninsular reservoirs due to *Microcystis* blooms. An oxycline is a basic feature in any productive reservoir. Deep tropical and sub-tropical reservoirs show a stable clinograde (i.e, decreasing DO levels with depth) with sharp fall in oxygen concentration at the hypolimnion, which mostly occurs during pre-monsoon. The longer the duration of such stability the more productive is the reservoir. Highly productive water should have a DO concentration of more than 5 mg/l. However, a very high concentration of DO leading to super saturation may become lethal to fish fry, as has been seen in some reservoirs predominantly infested with *Microcystis* blooms.

Free carbon dioxide

In some of the reservoirs, free from macrophytic vegetation or being confined to limited littoral zone only, free CO_2 was in trace or absent at surface waters. In contrast, a substantial amount of free CO_2 was found in surface waters in the major reservoirs of Madhya Pradesh in the range from 2.0 to 42.0 mg/l in Bargi, Tawa and Halali (Unni, 1993) and 16.0 to 30.0 mg/l in Rihand (Singh *et al*., 1980).

pH

Due to natural buffering capacity of water, Indian reservoirs seldom show drastic pH fluctuations. However in general, water pH is low during the monsoon due to dilution of alkaline substances or dissolution of atmospheric CO_2 with a resultant increase in the post-monsoon and pre-monsoon periods. The majority of the reservoirs have moderately alkaline pH due to alkaline soil reaction.

Specific conductivity

Specific conductivity is an index of the amount of water soluble salts present in water. Barring West Bengal and Jharkhand, most of the reservoirs in other states recorded conductivity in the range 100 to 300 mS/cm with some exceptionally higher values in case of reservoirs in Rajasthan and Haryana (Table 4). In normal freshwater, chloride content lies within 10 to 30 mg/l; if the value is somewhat more than this, it indicates local pollution. The average chloride content (mg/l) in reservoirs was in the range 7-30 with higher values observed during the pre-monsoon months in some reservoirs of Rajasthan and Haryana (Table 4). In freshwaters, electrical conductivity is also considered to be an index of productivity when the ionic composition is dominated by CO_3^- and HCO_3^- system because conductivity is known to be related to total dissolved solids (Henderson and Welcomme, 1974).

Table 4. Ranges of physico-chemical characteristics of some reservoirs in different stages.

State	Transparency (m)	Alkalinity (ppm)	Conductivity (µS/cm)	Chloride (ppm)
Jammu & Kashmir	0.1-0.8	46-112		
Himachal Pradesh	115-180	46-84	95-166	11-14
Punjab	0.5-1.0	73-198	168-300	12-15
Haryana	0.4-1.0	114-205	213-764	27-86
Rajasthan	0.3-1.5	40-256	142-959	7-70
Uttar Pradesh	0.2-3.4	44-164	72-280	3.5-25.0
Madhya Pradesh	0.2-1.5	81-170	124-337	14.5-44.5
Bihar & Jharkhand	0.1-1.1	43-63	12-306	14-65
West Bengal	0.1-1.2	40-125	28-154	12-34

Alkalinity

The majority of reservoirs have shown moderate total alkalinity within the range of 40 - 205 mg/l representing moderate productivity trends (Table 4). The low values of total alkalinity in Jharkhand and Bihar reservoirs are due to the acidic basin soil of lateritic type originating from dry forest areas; the dominance of carbonate is least pronounced in these reservoirs. In general, total alkalinity is high during pre-monsoon with a substantial decrease in the monsoon period due to dilution.

Nutrient status

In Indian reservoirs, available-N (NO_3 + NO_2) in water is typically very low (Table 5) throughout most of the year except in monsoon and to some extent for a shorter period during the pre-monsoon period. In the monsoon its availability is due to run-off from fertile catchments and in summer it is due to a faster rate of decomposition of bottom organic load, rendering nitrogen availability to standing water phase. The peak values of nitrate–N are encountered in the monsoon months and to a lesser extent in pre-monsoon periods.

In Indian reservoirs, except for a shorter period during the monsoon, the availability of phosphate is of a very low order and rarely exceeds 0.1 mg/l (Table 5). The lack of these nutrients in water does not seem to be indicative of low productivity, particularly in reservoirs free from pollution because of their rapid turnover and quick recycling e.g. 95% of the phosphorus is taken up by phytoplankton within 20 minutes while some algae can convert inorganic phosphate into more insoluble organic state within one minute (Hayes and Philips, 1958).

Table 5. Ranges of basic nutrients in water of some reservoirs in different states.

State	Nitrate-N (ppb)	Phosphate-P (ppb)	Silicate-Si (ppm)
Himachal Pradesh	10-250	40-150	3.0-5.5
Punjab	10-300	10-200	2.5-4.4
Haryana	10-150	5-200	1.6-3.8
Rajasthan	5-2020	10-280	0.27-11.21
Uttar Pradesh	10-430	20-650	3.1-9.5
Madhya Pradesh	5-469	5-180	0.8-8.5
Bihar & Jharkhand	5-600	2-330	1.3-33.0
West Bengal	5-96	0-110	2.2-7.4

Biological features of reservoirs

Plankton takes the lead role in maintaining trophic structure as neither the macrophytes nor the periphyton get a strong hold due to draw down effects and high flushing rates in Indian reservoirs. The plankton trends in some reservoirs are given in Table 6.

In most of the reservoirs studied, green algae and blue-green algae form the bulk of the plankton community followed by diatoms. The occurrence of Microcystis is significant. Among zooplankton, copepods are important followed by cladocerans, rotifers and protozoans. Altitude plays an important role in the distribution of *Microcystis*. In Gobindsagar, which is a productive sub-temperate reservoir, *Ceratium* sp. was dominant over *Microcystis*. The Rajasthan reservoirs which receive scanty rainfall and have poor flushing rates favour macrophytes and blooms of *Microcystis* are not recorded. Plankton usually exhibits two peaks in a year; a distinct winter pulse attributed to nutrient rich higher monsoonal inflow and a summer pulse of lower magnitude. Monsoonal pulses have also been observed in some reservoirs.

Table 6. Plankton trends in some reservoirs of different states.

State	Phytoplankton (%)	Zooplankton (%)	Plankton (units/l)
Himachal Pradesh	80	20	114-198
Punjab	58-87	12-42	319-435
Haryana	75-76	23-24	490-664
Rajasthan	70-85	15-30	583-4503
Uttar Pradesh	70-85	15-30	250-1500
Madhya Pradesh	60-94	6-40	150-3550
Bihar & Jharkhand	67-94	6-33	200-3000
West Bengal	70-80	20-30	150-500

Macro-benthos

According to the studies reported (Katiha *et al.*, 2007), shallow reservoirs such as Bachhra, Baghla, Kerwa and Dahod were found to be particularly rich in benthic fauna due to favourable substratum, rich organic matter and minimal water level fluctuations. The deeper reservoirs like Rihand had poor benthic macrofauna whereas the reservoirs like Chamera with a rocky and gravely bottom had no macrobenthic communities. Dipterans were most important in the reservoirs followed by gastropods, bivalves, annelids and other oligochaetes. The importance of bottom fauna in relation to fish yield in reservoirs has been highlighted by Hayes (1957).

Macrophytes

Some reservoirs have a good growth of macrophytes due to low flushing rates, e.g., Ramgarh, Jaisamand (Rajasthan), Bachhra, Baghla, Pahuj (Uttar Pradesh), Halali and Dahod (Madhya Pradesh). The biomass has varied from 0.2 to 5.2 kg m^{-2} wet weight. The peak is visually observed in summer and decreased during the monsoon season. Macrophytes were mostly submerged, emergent and floating types and were always dominant in the littoral areas. Macrophytes provide substrata to many insects, molluscs and other invertebrates. They accumulate large quantities of inorganic nutrients affecting phytoplankton growth adversely. The submerged weeds give shelter to minnows, which compete with major carps for food. Heavy growth of macrophytes prevents light penetration and cases of fish mortality due to heavy macrophyte growth have been recorded from Rajasthan. They also pose serious problems in the operation of fishing gear.

Among the macrophytes *Potamogeton* was predominant while *Hydrilla*, *Vallisneria*, *Ceratophyllum* and *Najas* were also recorded. These are generally impediments for operation of fishing nets but during monsoon, these submerged macrophytes facilitate the collection and anchoring of fish eggs.

Primary productivity

The gross primary production (GPP) in the reservoirs was in the range of 25-950 mg C m^{-3} hr^{-1} (Table 7) with wide temporal variations. Assimilation efficiencies were very moderate (55.40-74.30 %) signifying that these water bodies are moderately productive.

The estimated fisheries potential based on GPP varied from 45-545 kg $ha^{-1}yr^{-1}$ in different states. The existing fish yield was very low as compared to the potential. Based on primary production trends Natrajan and Pathak (1983) worked out energy flow estimates in some reservoirs in India, which gives an approximate estimate of potential food chain behaviour in the ecosystem.

Table 7. Ranges of gross primary production (GPP) in some reservoirs in different states in different states.

State	GPP (mg C m^{-3} day) $^{-1}$
Himachal Pradesh	1,008 - 1,560
Punjab	2,016 - 2,784
Rajasthan	1,440-3,936
Uttar Pradesh	600-2,640
Madhya Pradesh	936-22,800

Fish and fisheries in reservoirs

Species composition

According to the available information in India, the fish species contributing to the fisheries of the reservoirs located in the upper reaches of the rivers of Ganga system are mahseer *viz*. *Tor putitora*, *T. mosal*, *T. tor*; the katli, *Acrossocheilus hexagonolepis*; the snow trout, *Schizothorax plagiostomus*, medium carps, *Labeo dero* and *L. pangusia* and the goonch, *Bagarius bagarius*. The reservoirs located in the middle and lower reaches of the rivers harbour the Indian major carps, *Catla catla*, *Labeo rohita*, *Cirrhinus mrigala* and *Labeo calbasu* and other carps such as *Labeo gonius*, *L. bata*, *L. boga*, *L. boggut*, *Puntius sarana* and *Chagunius chagunio*. The major catfish species contributing to the fisheries of the reservoirs of the Ganga river system are *Wallago attu*, *Silonia silondia*, *Pangasius pangasius*, *Rita rita*, *Aorichthys aor*, *A. seenghala* etc. Smaller catfishes represented in these reservoirs are *Clupisoma garua*, *Eutropiichthys vacha*, *Mystus cavasius*, *Ompok bimaculatus* etc. The formation of reservoirs has adversely affected the indigenous fish stocks of the mahseer, snow trout, *Labeo dero* and *L. dyocheilus* of the Himalayan streams.

Status of fisheries

In Himachal Pradesh, the two large reservoirs, Gobindsagar (16867 ha) on river Sutlej and Pong (24,629 ha) on river Beas and a newly constructed small reservoir Chamera (900 ha) on river Ravi are highly productive. Despite their location in northern latitudes, subject to low temperatures, high yields are achieved. The annual fish yield of Gobindsagar reservoir has increased from 17 kg/ha (1975) to 96.4 kg/ha (1992-93), which is very high when compared to the national yield rate of large reservoirs (11.43 kg/ha) in India. The exotic silver carp (*Hypophthalmichthys molitrix*) alone contributed about 80% of the total catch. The silver carp accidentally entered into the reservoir, has negatively impacted the fishery of Indian major carps. The Indian major carps used to contribute 52% of total catch in 1976-77 but by 2003-04 contribution had decreased to 5% and exotic species comprised 92% of total fish catch. As silver carp is of low economic value, highly perishable and of low consumer preference, stock enhancement through silver carp is not preferred. As such, it has been proposed that the fishery dominated by higher valued Indian carps be re-established.

In Rajasthan, a number of small and medium reservoirs (407-3618 ha) investigated during 1997-2002 showed a fish production of 7.0-46.9 t/yr (14.9-172.3 kg/ha). In these reservoirs, major carps were dominant followed by minor carps and catfishes. In Ramgarh reservoir (1,260 ha), fish catch ranged from 18 to 141 kg/ha (average 77.80 kg/ha) during 1969-70 to 1984-85. Mrigal *C. mrigala* (33%) was the most important followed by catla *C. catla* (15 %) and rohu *L. rohita* (14 %) by weight in the commercial catches. Species such as *Notopterus notopterus*, *L. bata* and *Puntius sarana* were the next most numerically abundant group of fishes. Jaisamand (7,286 ha), the oldest reservoir in Rajasthan registered high fish yields (47.2-88.8 kg/ha) during 1962-70. *L. rohita* was the most dominant followed by *C. mrigala*, *Aorichthys seenghala* and *L. fimbriatus*. Specimens of catla weighing 39 kg were common until 1964. Mahseer weighing 3 kg were also available. Subsequently, the minor carps mainly *L. gonius* dominated the catch. After introduction of tilapia (*O. mossambicus*) into this reservoir, the carp fishery collapsed and at present tilapia essentially supports the fishery of the reservoir.

In Uttar Pradesh, Rihand (46,538 ha), one of the important large reservoirs popularly known as 'catla mine' had a dominance of *C. catla* (73-99 %) from 1971-72 to 1980-81. After its impoundment in 1962, the reservoir was stocked with seed collected from river Sone and the reservoir was well managed by Uttar Pradesh State Fisheries Department. Catla was well-established in this reservoir with three morphotypes (Deasai, 1993). Of these, one exclusively feed on zooplankton and the other two consume *Microcystis*, the most dominant phytoplankton in the reservoir. The fishery of catla later declined due to pollution with the establishment of five thermal plants around this reservoir. Fishers tended to use large mesh (140-180 bar size) gillnets targeting bigger sized (900-1100 mm; 15-25 kg) catla. However, due to failure of catla breeding, discontinuation of stocking and pollution, the catla fishery has collapsed.

Studies conducted by CIFRI in small reservoirs have documented a number of success stories. Small reservoirs *viz*. Gulariya, Bachhra, Baghla in Uttar Pradesh have shown a three fold increase in fish production ranging from 50 to 150 kg/ha (Jhingran, 1986). The culture-based capture fishery management measures were instrumental for remarkable enhancement in fishery of these reservoirs. The yield potential of Gulariya reservoir was reported to be 234 kg/ha which resulted from a stocking rate of 500 fingerlings/ha. The production increased from 8 t to 22 t (150 kg/ha) after application of the new management package.

In Madhya Pradesh, among the large reservoirs, Gandhisagar reservoir (66,000ha) registered the maximum fish yield of 3,424 t (52 kg/ha) during 1994-95. The fish yield of Gandhisagar has declined in the past five years averaging 1,676 t (26 kg/ha). *C. catla* is the main constituent species in the fishery (60-70 %). Catla in the size groups 750-850 mm dominated the fish catch during 1972-74, which later shifted to 850-950 mm (IV-V year age class) in subsequent years (Dubey and Chaterjee, 1977) *L. rohita* and *C. mrigala* also contribute significantly to the fishery of the reservoir. The reservoir was devoid of catla in the pre-impoundment period but after stocking, a breeding population with natural recruitment was established resulting in high yields. In another large reservoir Halali (7,712 ha) the annual fish yield varied from 73.5 t (15 kg/ha) to 350.7 t (73 kg/ha) with an average of 193.8 t (40 kg/ha) during 1990-2001. The local small-sized species (36.3%) represented by *L. calbasu* (below 0.5 kg), *N. notopterus*, *L. bata*, *L. gonius*, *C. reba* and *Mystus* spp. were dominant. The local major species (30.9%) represented by *L. calbasu* (above 0.5 kg), *A. aor*, *A. seenghala*, *W. attu*, *Notopterus chitala*, *O. pabda*, *Mastacembelus* and *Channa* spp. also occurred significantly in the catches. The major carps contributed 17.3% only with *C. catla* (9.0%), *L. rohita* (6.4%) and *C. mrigala* (1.9%). It was observed that in spite of stocking of major carp species a sizeable numbers the fishery of these was not established in Halali. The recapture rate of major carps in relation to stocking was very poor being only 2%.

In small reservoirs the annual fish yields typically range from 31 to 72 kg/ha. In Kerwa reservoir (482 ha), major carps (93.5%) with the dominance of *C. catla* (74.4%) were most significant until 1993-94. Its fishery declined (20%) thereafter with a remarkable increase in local minor species (74.5%). Medium carps, small-sized catfish and minnows represented this group. The contribution of mahseer to the catches of which was poor earlier (0.4-2.4%), has now increased to 5-10%. The hilly catchment area is favourable for breeding and propagation of mahseer. The rocky bed, submerged aquatic plants, molluscs and insects are also suited mahseer. The Government of Madhya Pradesh has reserved this reservoir for the development of a sport fishery for mahseer. Mathew (1969) reported that in Gobindgarh reservoir (307 ha) there was sharp variation in yield varying from 0.4 to 26.4 kg/ha (average 15.9 kg/ha). Indian major carps *C. catla*, *L. rohita*, *C. mrigala* and *T. tor* constitute 90 % of the catch and the predators are negligible. The major carps breed in the reservoir. *T. tor* is one of the local species, which contributes substantially to the catch. Carps, especially catla registers impressive growth, and specimens weighing 12 kg commonly occur in the catches. Incidental catches of very large catla (40 kg) have also been reported from this reservoir. The average size of rohu and mrigal in the catch are 3 and 5 kg respectively, while the mahseer, *T. tor* grows to a smaller size but outnumbers the other fishes in total weight of the catch. Pal (1979) reported that Kulgarhi reservoir (193 ha) exhibited poor fish production (average 7.4 kg/ha). The fish catch was represented by *C. catla* (75.6 %), *C. mrigala* (11.5 %), *L. rohita* (8.3 %) and hybrids of carps (2.5%). This was the first reservoir in India, where the exotic silver carp (*H. molitrix*) was first introduced on an experimental basis. The silver carp has adversely affected the growth of catla in the reservoir as both the fishes compete for food resources.

Fishing practices

Gear

The major fishing gear in reservoirs is surface gillnets of different mesh sizes (20-150 mm bar size). The standard size of gill net is 50 x 2 m with a head rope and floats and footrope with or without sinkers. The net is made of nylon twine. Presently, the plastic twine (mono-filament) nets are also being commonly used in the reservoir fisheries. About 77 % of the catch is entangled and the rest is gilled. Dragnets (shore seine) are also used in some reservoirs, especially for catching catfishes and weed fishes. In Uttar Pradesh and Madhya Pradesh, the dragnets are called 'mahajal'. The other fishing gears such as cast nets, scoop nets, long lines and traps are also operated but the catches are insignificant.

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

Fishing craft

Coracle, a saucer shaped country craft, is the major fishing craft used in the reservoirs of peninsular India. It is made of a split bamboo frame, covered with buffalo skin. Apart from being simple and inexpensive, coracle is durable and has very good manoeuvrability in waters. It is also a versatile craft used for laying and lifting of nets, besides navigation and transport of fish and other material. Coracles of Krishnarajasagar are prepared by wrapping HDPP over the bamboo frame with the help of coal tar as an external covering in place of buffalo skin. This modified version of coracle is cheaper and more durable (Parameswaran and Murugesan, 1984).

Unlike Gobindsagar, where all the fishers possess their boats, reservoir fishers, in general, are too poor to own boats. In many reservoirs like Vallabhsagar and Hirakud, the fishers could get their boats through a subsidy and other financial assistance from the Government or funding agencies. In Vallabhsagar, boats are distributed by the State among the fishers at a subsidy of 50 % from various government-sponsored schemes. Wooden boats are used for fishing in a number of reservoirs, especially in the North India. Flat-bottom, locally fabricated boats ranging in length from 3 to 7 m are used in Kyrdemkulai, Hirakud, Malampuzha, Gobindsagar, Gandhisagar and Rihand. A plank-built, flat-bottom canoe of 2 - 3 m in length is the most popular fishing craft of Gandhisagar.

Mechanised boats are not used in reservoir fishing to any appreciable extent. A 9.1 m long wooden, mechanised boat has been introduced by the CIFT (Central Institute of Fisheries Technology) in Hirakud reservoir, but these are too expensive for the fishers. It is important to note that large water bodies like Nagarjunasagar, Tungabhadra and Krishnarajasagar have no motorised crafts either for fishing or for fish transport.

Dugout canoes, carved out of palm trees are used in Yerrakalava reservoir. In most of the reservoirs in the country the fishers rely on improvised materials. In a majority of Indian reservoirs, where the catch is not very rewarding, no boats are used and the fishers depend entirely on these improvised devices.

Fish production trends

In India, reservoirs are under-exploited with an average annual fish yield of 20.15 kg/ha, with mean production in small, medium and large reservoirs being 48.05 kg/ha/year, 12.39 kg/ha and 11.31 kg/ha, respectively. In the case of small reservoirs, Madhya Pradesh (47.26 kg/ha/year) and Rajasthan (46.43 kg/ha/year are important states in terms of fish production. The contribution of medium reservoirs to reservoir fish production is comparatively higher from Rajasthan (24.47 kg/ha/year). The fish yield of large reservoirs in Madhya Pradesh (40 kg/ha/year) and Himachal Pradesh (35.55 kg/ha/year) is high as compared to the reservoirs of other states. However, the overall fish yields from reservoirs remained very low (Table 8). This is mainly due to poor management as a result of the lack of understanding of reservoir ecology, trophic dynamics,

Table 8. Average annual fish yields from reservoirs in different states of India (kg/ha).

State	Small	Medium	Large	Pooled
Tamil Nadu	48.5	13.7	12.7	22.6
Uttar Pradesh	14.6	7.2	1.1	4.7
Andhra Pradesh	188.0	22.0	16.8	36.5
Maharashtra	21.1	11.8	9.3	10.2
Rajasthan	46.4	24.5	5.3	24.9
Kerala	53.5	4.8	-	23.4
Bihar	3.9	1.9	0.1	0.1
Madhya Pradesh	47.3	12.0	14.5	13.7
Himachal Pradesh	-	-	35.7	35.6
Orissa	25.9	12.8	7.6	9.7
Average	**49.5**	**12.3**	**11.4**	**20.1**

inadequate stocking, wrong selection of species for stocking, low size of stocking materials and irrational exploitation. Adopting the available package of practices, developing the necessary infrastructure facilities and providing conducive socio-economic environment, can bridge the existing wide gap between the potential and the actual yield.

Based on hydrological condition and primary productivity, the large reservoirs have a production potential of 65-190 kg/ha, the medium reservoirs 145-215 kg/ha and small reservoirs 285-545 kg/ha per year. There is a wide gap between potential and the actual yield, which can be mitigated achieving 70-80% of the potential through proper scientific management.

The fish yield of most of the Gangetic Basin reservoirs was less than overall average of the country, barring medium reservoirs, which was marginally higher. Overall the fish yield was maximum in the state of Himachal followed by Rajasthan and Madhya Pradesh (Table 9). Considering the existing and potential fish productivity, reservoirs have very good scope for increasing fish production and productivity (Table 10).

Table 9. Average annual fish yields in reservoirs in different states in India.

State	Yield (kg/ha)			
	Small	Medium	Large	Total
Madhya Pradesh	47.3	12.0	14.5	13.7
Bihar	3.9	1.9	0.1	0.1
Uttar Pradesh	14.6	7.2	1.1	4.7
Rajasthan	46.4	24.5	5.3	24. 9
Himachal Pradesh	-	-	35.6	35.6
Total for IGB states	29.8	12.8	9.2	18.3
Total India	49.9	12.3	11.4	20.1

Table 10. Production potential of small reservoirs in India (kg/ha/year).

Reservoir (ha)	Potential	Actual
Manchanbele (329)	694	118
Aliyar (320)	250	193.8
Thirumurthy (388)	268	213
Sarni (1012)	140	56
Nelligudda (80)	840	1825
Kyrdemkulai (80)	571	-
Gulariya (300)	200	150
Bacchra (140)	240	139
Baghla (250)	200	104
Govindgarh (307)	220	60
Kulgarchi (193)	45	7.4
Loni (350)	36	27

Efforts in yield enhancement

Various efforts have been made in the country to scientifically manage the reservoir fisheries. These attempts have been made by CIFRI and other organisation in linkage with the state department which control and own the reservoirs. Some of the successful trials are summarised in Tables 11 and 12. However, unfortunately no horizontal expansion could take place due to various constraints faced by the state departments.

From Tables 11 and 12, it can be seen that it is possible to achieve the potential target production especially from small reservoirs in India. Therefore, scientific management, if continued on a long-term sustainable basis, by the reservoir owners of the state departments, will significantly increase the overall reservoir fish production. This will help the livelihoods of large number of people in comparison to benefiting only a few in aquaculture activities, which in the long run have environmental implications too.

Table 11. Increase in fish yield from medium and large reservoirs after management intervention.

Reservoir	State	Yield (kg/ha/year)	
		Before	After
Yeldari	Maharashtra	3.0	37.0
Girna	Maharashtra	15.0	45.0
Ravishankersagar	Chhatisgarh	0.22	1.5
Gandhisagar	Madhya Pradesh	1.00	44.0
Tawa	Madhya Pradesh	1.4	28.0
Ukai	Gujrat	30.0	110.0
Gobindsagar	Himachal Pradesh	20.0	100.0
Pong	Himachal Pradesh	8.0	64.0
Bhawanisagar	Tamil Nadu	30.0	94.0
Santhar	Tamil Nadu	26.0	108.0

Table 12. Increase in fish yield from small reservoir after management intervention.

Reservoir	Location State	Yield (kg/ha/year)	
		Before	After
Chulliar	Kerala	35.0	275.0
Meenakara	Kerala	10.0	105.0
Markonahally	Karnatka	5.0	70.0
Gulariya	Uttar Pradesh	3.0	170.0
Bachra	Uttar Pradesh	NA	150.0
Bahgla	Uttar Pradesh	NA	110.0
Thirumoorthy	Tamil Nadu	70.0	200.0
Aliyar	Tamil Nadu	27.0	215.0

Management practices

Fisheries are under individual state control in India and there is a great deal of variation in the management practices followed by different states ranging from outright auctioning to almost free-fishing access. Cooperative societies and the state-level fisheries development corporations are also involved in fishing and marketing operations. The nature of their involvement and their role in the fishery and market interventions often varies from one reservoir to another within the same state. Reservoirs in India, with very few exceptions, are public water bodies owned by government departments such as those responsible for irrigation and power generation. In many cases, management of their fisheries is handed over to the fisheries departments. The management options for developing fishery in lakes and wetlands in different river basins in India have been highlighted by Vass (2007b, c) those with suitable modification could be tested in small reservoirs on a pilot scale.

Fishers are required to obtain a license from the local office of the state fisheries department. The state department authorities determine the number of fishers and fishing units to be operated in a reservoir. Since the mesh regulations and the decisions regarding closed seasons are policy matters, the directorate at the state capital determines such regulations. In some states such as Madhya Pradesh and Himachal Pradesh, the fisheries development corporations are responsible for managing reservoir fisheries. These corporations act as overseeing bodies for the numerous cooperative societies that are operating in the reservoirs, and they undertake marketing functions to ensure that fishers get the correct price for their catch. However, their market interventions have not markedly benefited the fishers.

Normally, the department of fisheries stocks fish fingerlings in the reservoirs free of charge and offers a number of loans and subsidies to fishers for the procurement of nets and boats. The amount of subsidies and the nature and terms of the loans vary from state to state. The states are generally quite liberal so that fishing is virtually free-for-all. This is one of the reasons why accurate statistics are impossible to obtain.

In some states, the departments owning the reservoirs have not handed over the fishing rights to the fisheries department, in which cases they directly manage the fisheries. Sometimes Forest and Wildlife Department or Tourism Department owns the reservoirs.

The commercial exploitation systems followed in different states can be summarised as:
- Departmental fishing.
- Lease by auction.
- Issue of licenses for fishing.
- Fishing on royalty (crop sharing).

Direct departmental fishing, being uneconomical, is practiced in a handful of reservoirs. In some reservoirs such as Hirakud, Nagarjunasagar, and DVC, departmental fishing is carried out for experimental and exploratory purposes. In most cases, the department exerts its control over the exploitation by acting as a marketing link and controlling the fishing effort. In Rajasthan, Madhya Pradesh and Uttar Pradesh, the small reservoirs are mostly auctioned on yearly basis. In a number of large reservoirs, free unlimited licenses are issued to fishers. This virtually free-for-all system has been found to be detrimental to the fisheries in Nagarjunasagar, Yerrakalava and a large number of reservoirs in Andhra Pradesh (Sinha and Katiha, 2002).

Crop sharing is a very popular mode of exploitation in Tamil Nadu, where the fishers are provided with all fishing implements, in exchange for a royalty payment from the landings (sometimes up to 50 % of the catch) to the state government. In many cases, licenses are issued either free of charge or for a very small nominal fee. Reservoir fisheries development is also often linked to many social welfare and relief activities under village and district administrations. In such cases, immediate social goals are pursued overlooking long-term effects on the fish stocks.

Socio-economic and institutional settings

In India, very few studies have been carried out on the socio-economic status and institutional framework of reservoirs, particularly with reference to fishing activities. In most reservoirs, fisheries have been developed as a secondary user so that the fisheries component was missing during the planning phase of reservoir construction. As a result, there were no fisheries-related studies during the pre-impoundment phase. In most reservoirs, impediments to fishing such as submerged tree stumps, rocks, etc. are present and their removal after the construction of reservoir is costly. Representation from fisheries authorities in the reservoir management boards is therefore important for better fisheries management of the reservoirs. These water bodies, if managed properly for fisheries operations, have been proven to be very effective in enhancing income of rural communities in addition to providing employment opportunities as in the case of Gobindsagar and Pong Dam reservoirs in Himachal Pradesh (Katiha, 1994).

Since reservoir fisheries are generally considered a secondary activity, compared to the irrigation and hydro-power generation, the department of fisheries or other fisheries agencies generally obtain the fishery management rights from the owners of the reservoirs, either by paying some royalty or nominal amount (Rihand in Uttar Pradesh and Kansbati in West Bengal) or free (Gobindsagar and Pong Dam in Himachal Pradesh). In some situations the Fisheries Department transfers the fishing rights to some other government agencies, co-operatives or private agencies and receives the royalty with or without rendering any fisheries development services.

One of the most important institutional arrangements for exploitation of fishery resources in reservoirs is a 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 status of fisheries resources of the state. In Uttar Pradesh and Rajasthan, the reservoirs with area i) below 100 ha are leased every year, ii) 100-500 ha for 3 years, iii) 500-1000 ha for 5 years, and iv) above 1000 ha for 10 years. In Madhya Pradesh, reservoirs below 100 ha are under the control of Gram Panchayat (i.e., the local level administrative institution) for fisheries management, while reservoirs of 100 – 1000 ha are under Department of Fisheries and those above 1,000 ha are under the State Fisheries Corporation. Past experience has revealed that reservoirs entrusted to state agencies for management of fish stocks through stocking and control of harvesting have consistently maintained a good production level, while those under the control of private contractors have not been encouraging. Where the fisheries management was vested with co-operatives, the results have been moderate, but proper supervision at stocking and fish harvesting stages is required.

When reviewing the fisheries management practices for various sized reservoirs, the appropriate management strategies for large and medium-sized reservoirs should involve stock enhancement aspects, while for the small reservoirs, culture based management is considered to be appropriate.

The unavailability of reliable catch statistics and yield estimates in reservoirs is a major setback for defining scientific management strategies for Indian reservoirs. More discomforting is the fact that the production figures available on most of the reservoirs are inaccurate and unreliable. This lacuna is attributed to several factors, chiefly:

- The multiplicity of agencies owning fishing rights creating difficulties in gathering data in some states.
- Highly scattered and unorganised market channels, mostly under the clutches of illegal money lenders.
- Ineffective cooperative set ups.
- Diverse licensing/royalty/crop sharing systems practiced by different state governments, some of which include a free-for-all system, providing little scope for recording catch statistics.
- Inadequate and poorly trained manpower at the disposal of state governments and cooperatives to collect catch data, follow statistically sound sampling procedures and to cover the whole reservoir.

There is a need to merge the twin objectives of conservation and yield optimisation in reservoir fisheries management. While the fishers and the fish vendors strive to increase the production to maximise profit, it is the responsibility of the state to ensure that economic expediency of development does not mar ecological reasoning. The virtually open access nature of fisheries exploitation, as practiced in Andhra Pradesh, is counter–productive to resource conservation and management. Although there are fair possibilities of linking reservoir fisheries development with poverty alleviation programmes, the progress made thus far in this direction is not overly encouraging. The chances of creating additional employment are not high in the majority of Indian reservoirs. On the contrary, many reservoirs have surplus manpower, which could be diverted to other reservoirs, enabling them to continue fishing without adverse effect on the income level of the existing fishers (Paul and Sugunan, 1990).

Proposed action plan

Measures to increase reservoir fisheries productivity include:

- Extensive transfer of technological backstopping to the State Department of Fisheries and grass root level fishers/fisher organisations.
- Re-appraisal of present state policies for the ownership, fishing rights and fisheries management, leasing (lessee, lease tenure and amount) to encourage the reservoir fisheries development activities.
- Enforcing appropriate guidelines for stocking and other management protocols, strict monitoring of stocking and harvesting schedules. This may include:
  - Issue notification for close season or fishing-holiday during the breeding season.
  - Declaration of the lotic sector of reservoir as a highly sensitive and protected area during the breeding season.
  - Effective enforcement of size and mesh regulations to conserve the breeding stocks.
  - Strict monitoring and prohibition of exotic species to build or conserve the stocks of economically viable and region specific fish species.
- A partnership approach may be encouraged by involving various user groups, such as irrigation, agriculture, fisheries and environment departments to provide enabling environment for sustainable fisheries, eg. the irrigation authorities to assure minimum required level of water in reservoir for safe maintenance of biotic communities and information about opening of sluice gates to be shared with the fisheries department.
- Authorities to recognise fisheries as an important activity in reservoirs.
- Adoption of various options for stock and species enhancement for management of reservoir productivity including the pens and cages.
- Infrastructure support to provide desired quality and quantity of fish seed in time and space.
- Minimising losses by way of escape of fish through spillways and canals through designing suitable screen structures and their annual repairs.
- Introduction of community-based/co-management concepts considering the multiple use, multi-stakeholder environment in Indian reservoirs.
- Inclusion of fisheries experts in committees at the start of large water diversion projects and schemes.
  - Giving due importance for fishery activities at the pre-impoundment and/or planning stage of proposed reservoir.
- Providing infrastructure and credit support for marketing and post-harvest activities in reservoir fisheries.
- Development of mechanisms for long-term generation of a reliable database on reservoir fisheries including the morphometry, catch and fisher statistics, management and property regimes.
- Organising trainings and refresher courses for the personnel from state fisheries departments, reservoir managers, NGOs and other stakeholders to upgrade their knowledge on reservoir fisheries and ecological management.

- Viable schemes for financial assistance to fishers depending upon reservoir fisheries for their livelihoods.

Acknowledgement

The authors are grateful to the authorities in ICAR for permission to attend the Regional Consultation on Asian Reservoir Fishery Development at Bangkok. We also wish to record our thanks to the authorities at NACA Secretariat for providing financial support, which enabled us to attend the consultation.

References

Anon., 2006. XI Five Year Plan for Fisheries, *Report of the Working Group, Planning Commission*. Government of India, New Delhi.

CIFRI,1986 - *Annual Report*. Central Inland Fisheries Research Institute, Barrackpore, Kolkatta.

CIFRI, 2006 - *Annual Report*. Central Inland Fisheries Research Institute, Barrackpore, Kolkatta.

Desai, V.R., 1993. Fisheries of Rihand Dam - progression and retrogression. In: (Jain, R.K., ed.). *Advances in fisheries and fish production*. Hindustan Publishing Co., Delhi.

Desai, V.R.,Singh, R.K., 1979 Occurrence of thermocline in Rihand Reservoir of U.P. and its depth criterion in relation of reservoir level. *Journal of the Inland Fisheries Society of India*, 11(2): 69-72.

De Silva, S.S., 1988. Reservoirs of Sri Lanka and their fisheries. *FAO Fisheries Technical Paper* No. 298. Food and Agriculture Organization of the United Nations, Rome.

Dubey, G.P., Chatterjee, S.N., 1977. Case study of Gandhisagar reservoir, *Madhya Pradesh, India. Proceedings of Indo-Pacific Fisheries Council*, 17 (3): 232-246.

Hayes, F.R., 1957. On the variation in bottom fauna and fish yield in relation to trophic level and lake dimensions. *Journal of the Fisheries Resources Board Canada*, 14: 1-32.

Hayes, F.R., Phillips, J.E., 1958. Lake water and sediment, IV. Radiophosphorus equilibrium with mud, plants, and bacteria under oxidised and reduced conditions. *Limnology and Oceanography*, 3: 459–475.

Henderson, H. F., Ryder, R. A. Kudhongania, A.W.. 1973. Assessing fishery potentials of lakes and reservoirs. *Journal of the Fisheries Resources Board Canada,* 30: 2000-2009.

Henderson, H.F., Welcomme, R.L., 1974. The relationship of yield to morpho-edaphic index and numbers of fisherman in African Inland Fisheries. *CIFA Occasional Paper* No. 1. Central Institute of Freshwater Aquaculture, India.

Jhingran, A.G., 1986. *Reservoir Fisheries Management in India.* Bulletin No. 45, Central Inland Fisheries Research Institute, Barrackpore.

Katiha, P.K., 1994. *Natural Resource Management: A Case Study of Reservoir Fisheries in Himachal Pradesh.* PhD. Thesis, Unpublished. Department of Social Sciences, Dr. Y.S. Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh.

Katiha, P.K., Vass, K.K., Shrivastava, N.P., Sharma, V.K., Sarkar, S., 2007. Inventory of Reservoirs in Indian Indo-Gangetic Basin for fishery enhancements. Abstr. No. P 184. In: *Taal 2007 12th World Lake Conference*. Organised by MoEF GoI and ILEC, Japan.

Le-Cren, E.D., Lowe-McConnel, R.H., 1980. *The functioning of freshwater ecosystem*. Cambridge University Press, Cambridge.

Mathew, P.M., 1969. Limnological investigations on the plankton of Govindgarh lake and its correlation with physico-chemical factors. *Proceedings of the Seminar on Ecology and Fisheries of Freshwater Reservoirs, 27-29 November, 1969.* Central Inland Fisheries Research Institute, Barrackpore.

Natarajan, A.V., 1976. Ecology and state of fishery development in some of the man made reservoirs of India. In: *Symposium on the development and utilisation of Inland Fishery resources, Colombo, 27-29 October 1976.*

Natarajan, A.V., 1977. *Fifth Workshop of AICP on Ecology and Fisheries of Freshwater Reservoirs*. Ukai, 7-8 September, 1977.

Natarajan, A.V., 1979. Ecosystem oriented approach for reservoir fisheries development in India. *Souvenir on the ICAR Golden Jubilee Year, CIFRI, Barrackpore, West Bengal*, Part I, 107-111.

Natarajan, A. V., Pathak, V., 1983. Pattern of energy flow in tropical and sub-tropical impoundments. *Bulletin No. 36,* Central Inland Fisheries Research Institute, Barrackpore.

Pal, J.N., 1979. Physico-chemical features of Getalsud reservoir. *Proceedings of the Summer Institute on Capture and Culture Fisheries of the Man-made Lakes in India*. Central Inland Fisheries Research Institute, Barrackpore.

Paul, S., Sugunan, V.V., 1983. Fishing in reservoirs - certain economic considerations. In: *Proceedings of the seventh workshop on Ecology and Fisheries of Freshwater reservoirs, 9-10 March 1983*. Central Inland Fisheries Research Institute, Barrackpore, India.

Parameswaran, S., Murugesan, V.K., 1984. A note on an inexpensive coracele. *Indian Journal of Fisheries*, 31(3): 387–389.

Paul, S., 1990. Inland Fisheries marketing & marketing intervention. In Sugunan, V. V. and Bhawmik, U. (eds.) *Technologies for inland fisheries development*. Central Inland Capture Fisheries Research Institute, Barrackpore, India, 219 pp.

Paul, S. Sugunan, V.V., 1990. Development of reservoir fisheries, areas of hopes and despair. In: Jhingran, Arun G. and Unnithan, V.K. (eds.). *Reservoir Fisheries in India, Proceedings of the National Workshop on Reservoir Fisheries, 3-4 January, 1990*. Special Publication 3, Asian Fisheries Society Indian Branch, Mangalore, India.

Raghavan, S.L., Sukumaran, P.K., Govind, B.V., Naija, I., 1977. A case of fish mortality in Byrmangala reservoir. *Journal of the Inland Fisheries Society of India*, 9: 203-204.

Ramakrishniah, M., 1990. *Morpho-drainage Index, a fish yield predictor for Indian reservoirs*. Paper presented at the 2nd Asian Reservoir Workshop, Hangzhou, P.R. China, 15-19 October, 1990.

Rawson, D.S., 1952. Mean depth and fish production in large lakes. *Ecology* 33: 513–521.

Rawson, D.S., 1955. Morphometry as a dominant factor in the productivity of large lakes. *Verhandlungen des Internationalen Verein Limnologie*, 12: 164-175.

Sarkar, S.K., Govind, B.V., Natarajan, A.V., 1977. A note on some distinctive limnological features of Gobindsagar reservoir. *Indian Journal of Animal Science*. 47: 435–39.

Sarkar, S.K., 1979. Hydrological features of Konar and Tilaiya reservoirs with highlights on limno-chemical implications of thermal and chemical stratification. In: *Proceedings of the Summer Institute on Capture and Culture Fisheries of the Man-made Lakes in India*. Central Inland Fisheries Research Institute, Barrackpore.

Shrivastava, N.P., Das, A.K., 2003. Ecology and Fisheries of selected reservoirs of Madhya Pradesh. CIFRI Bulletin No. 118. Central Inland Fisheries Research Institute, Barrackpore.

Singh, R.K., Shrivastava, N.P.,Desai, V.R., 1980. *Journal of the Inland Fisheries Society of India*, 12(1): 100-111.

Sinha, M., Katiha, P.K. 2002. Management of inland fisheries resources under different property regimes. In: Marothia, D.K. (ed.) *Institutionalizing Common Pool Resources*. Concept Publishing Company, New Delhi.

Sreenivasan, A., 1989. Principles of ecology and fisheries management in man-made lakes. In: Jhingran, A.G. and Sugunan, V.V. (eds.). *Conservation and Management of Inland Capture Fisheries Resources of India*. Inland Fisheries Society of India, CIFRI, Barrackpore.

Sugunan, V.V., 1995. Reservoir Fisheries in India. *FAO Fisheries Technical Paper* No. 345. Food and Agriculture Organization of the United Nations, Rome.

Unni, K.S. 1985. Comparative limnology of several reservoirs in central India. Int. *Revue gesamten Hydrobiologia*, 70 (6): 845-856.

Unni, K.S., 1993. Limnology of Central Indian lakes, reservoirs and ponds - a review. In: Mishra, P.C. and Trivedy, R.K. (eds.). *Ecology and pollution of Indian lakes and reservoirs*. Ashish Publishing House, New Delhi.

Vass, K.K., 2007a. Indian Reservoir Fisheries Development – Constraints and Solutions. *Fishing Chimes*, 27(1): 76-81.

Vass, K.K.,- 2007b. *Comparative limnology of lakes in Indus, Gangetic and Brahamaputra basins in India*. Abstr. SIL Congress, Canada.

Vass, K.K., 2007c. Conservation and restoration of Lakes and Wetlands. Keynote Abstr. No. KN13 pp 12. In: *Taal 2007 12th World Lake Conference*. Organised by MoEF GoI & ILEC, Japan.

Vollenweider, R.A., 1969. *A manual on methods for measuring primary productivity in aquatic environment*. IBP Hand Book No. 12. Blackwell Scientific Pub., U.K. 213 pp.

Reservoir Fisheries in Nepal

Gagan B.N. Pradhan

*National Inland Fisheries and Aquaculture Development Programme,
Directorate of Fisheries Development, Kathmandu, Nepal.*

Introduction

Nepal is a relatively small, landlocked and mountainous country with an area of 147,181 km^2. It is endowed with abundant inland freshwater resources collectively covering about 0.82 million ha or nearly 3% of the country (DOFD, 2006). It is estimated that some 500,000 ha of water surface may be available for fish production, of which about 100,000 ha would be lakes, reservoirs and fish ponds (NARC, 1991).

Inland water resources - nature and distribution

The inland water resources in Nepal are broadly classified into rivers, lakes, reservoirs, ponds, swamps and irrigated farm lands. The extent and coverage of different types of water body is shown in Table 1.

Rivers

The major river systems in Nepal are the Koshi in the east, Gandaki in the central region, Karnali in the west and Mahakali in the far west. These river systems are fed by over 6,000 rivulets and streams originating in the high glacial Himalayan, Mahabharata and Siwalik Mountain regions, and cover an estimated area of 395,000 ha or 48% of total inland water resources of the country (DOFD, 2006). The rivers of Nepal form the part of the headwaters of the Ganges River Basin, one of the 20 largest rivers in the world. Discharge from Nepal contributes about 40% of the total annual flow of Ganges System and almost 70% of flow in the dry season (Water Resources Strategy of Nepal, 2002).

Lakes

Lakes of various sizes scattered all over the country covering an estimated area of 5,000 ha or about 0.6 % of natural waters. Lakes occur from southern low plains at about 60 m to more than 5,000 m altitude (Gurung and Wagle, 2000). The lakes above 3,300 m are not affected by human activities while those of the foot hills are affected to varying degrees by various human activities.

The lakes in Nepal are of three types: glacial lakes, tectonic and oxbow lakes. There are 44 major glacial lakes in the northern Himalayan region which are located above 4,000 m. Tectonic lakes occur in the hilly region. These lakes when drained were replaced by flat basins such as the Kathmandu valley, Banepa, Panchkhal, Mariphant (Palpa), Dang and Surkhet. Some famous lakes of tectonic origin in the mid-hills are Phewa (523 ha), Begnas (328 ha) and Rupa (115 ha). The age and origin of these lakes are not known. More than two dozen oxbow lakes are present in Nepal and most of them are located in Chitwan National Park, Nawalparasi, Bardiya and Kailali (Sharma, 1997) in the low altitude plains in the southern part of the country. Lakes are also classified as major and minor lakes. Some of the major lakes are - Rara Lake, Phewa Lake, Begnas Lake and Rupa Lake or Rupakot Lake. Minor lakes include Khaptad Lake, Baragon Lake, Tilicho Lake, Phoksundo Lake, Dudhpokhari Lake, Jageswar Lake and Panch Pokhari.

Reservoirs

Reservoirs are built to collect water to generate hydropower and/or for irrigation. In Nepal, there are two types of hydropower projects; run of the river type and traditional reservoir type. Run-of-the river type projects are small compared to reservoir type projects. Therefore, numerous small and large reservoirs are built in different parts of Nepal. Currently, the total extent of reservoirs is estimated at 1,500 ha comprising about 0.2% of the total water area in the country. Some of the important reservoirs are: the Indrasarobar reservoir (220 ha), which was impounded to produce hydroelectric power by damming the Kulekhani River in the mid hills; and the Jagdishpur reservoir (155 ha) which was impounded for irrigation by damming the Budhi Ganga River in the plains area. Other small reservoirs which have been built by run off scheme for irrigation and hydropower generation include Trisuli (16 ha), Marsyangdi (62 ha), Panauti (2 ha), Sunkoshi (4 ha) and several others. The potential for expansion of reservoir area in Nepal is estimated to be very high. A feasibility study on various river basins and systems indicated an additional 92,400 hectares of freshwater reservoirs are plausible: Gandaki basin, 45,000 ha (Prosser, 1978); Bagmati river system, 9,000 ha (Shrestha *et al.*, 1979); and Karnali river system, 38,400 ha (Himalayan Power Consultants, 1989) will be added upon their completion to the country's reservoir inventory. Additionally, a considerable area of more than 6,500 ha of fish ponds are situated in various parts of the country. There is also an estimated area of 12,500 ha of marginal swamps, while irrigated paddy fields cover about 398,000 ha in Nepal (Table 1).

Inland water resources - development potential

Hydropower generation

Nepal has a great hydropower potential estimated at 83.28 GW of electricity, out of which about 45.0 GW would be economically viable to exploit. Hydropower development in the country had been underway since 1911, but only a small fraction of about 0.527 GW has been exploited so far. The theoretical hydropower potential estimated on the basis of average flow is given in Table 2.

Table 1: Estimated water surface area in Nepal (DOFD, 2006).

Resource details	Estimated area (ha)	Coverage (%)	Potential area (ha)
Natural Waters	401,500	48.8	-
Rivers	395,000	48	-
Lakes	5,000	0.60	-
Reservoirs	1,500	0.20	92,400
Village ponds	6,500	0.80	14,000
Marginal swamps around Irrigated fields	12,500	1.40	-
Irrigated paddy fields	398,000	49	-
Total	**818,500**	**100**	

Table 2: The theoretical hydropower potential in Nepal.

Main energetic divisions	Area under count (in km²)	Hydropower potential (106 KW)
Sapta Koshi	27,300	22.35
Sapta Gandaki	31,600	20.65
Karnali & Mahakali	47,300	36.17
Southern Rivers	39,300	4.11
Total		83.28

Irrigation

Water resource development projects for irrigation are being implemented at an accelerated rate under national development strategies. A master plan for irrigation was developed in 1990 and the status of irrigation schemes in Nepal is given in Table 3.

Table 3. Irrigation status with respect to total land area, net agriculture and irrigable area in Nepal.

Ecological belt	Total land area (ha)	Net agriculture area (ha)	Irrigable area (ha)
Tarai (flat surface)	3,409,863	1,359,165	1,337,581
Hill	6,152,353	1,054,272	368,577
Mountain	5,186,183	227,198	59,918
Total	14,748,399	2,640,635	1,766,076

Biological aspects

In spite of the vast availability of Nepal's water resources and their great zoogeographical significance, only a few are exploited for fisheries purposes. The earliest record of fish and fisheries of Nepal goes back to the eighteenth century (Kirkpatrick, 1793). The first scientific report on fish fauna of Koshi and Rapti rivers were by Francis Buchanan (Hamilton) (1822). Similarly, the first study of fish fauna in Nepalese lakes was by Johan (1882) and this study focused on Phewa, Rupa and Begnas lakes of Pokhara Valley.

The first limnological work reported from Nepal was a study on some aquatic fauna in Kalipokhari from eastern Nepal (Brehm, 1953). The first comprehensive limnological investigation in Nepal was initiated by Loffler (1969) in high mountain lakes of Khumbu Himal. Hickel (1973) investigated the lakes of Pokhara valley during the research scheme of Nepal Himalayan Expedition.

Ferro and Swar (1976, 1978) conducted a survey on the biological and limnological conditions of lakes and natural water bodies in Pokhara Valley with reference to the existing fish populations, their feeding habits and biology. Pradhan (1982) did a preliminary study of Syarpu Daha, a mid hill lake of the western region located at an altitude of about 1,372 m and reported a single species of *Schizothorax*. Terashima (1984) had reported three new cyprinids of the genus, *Schizothoraichthys* from Lake Rara, north western Nepal. According to this investigator, these species are endemic to Lake Rara. Pradhan and Swar (1988) reported *Acrossocheilus* (*Neolissochilus*) *hexagonolepis* (katle), *Puntius chelynoides* (karange), *Tor tor* and *Schizothorax* (asala) from Indrasarobar Reservoir, Kulekhani and outlined the potential for expansion of fish culture in the reservoir. Aizaki (1986) studied the trophic status and water quality of high altitude lakes in Mount Annapurna region. Yadav (1994) worked on the water quality and benthic fauna of Palung, Thudo and Chitlang rivers. All these rivers drain into the Indrasarobar reservoir, Kulekhani. Gautam (2003) studied on the fish diversity and aquatic life resource of Lake Rupa, Kaski and recorded 23 species of fish belonging to six families and eighteen genera under five orders.

Indigenous fish such as Barilias barna, *B. bendelisis*, *B. vagra*, *Neolissocheilus hexagonolepis*, *Tor putitora*, *Chagunius chagunio*, *Noemacheilus* (*Acanthocobitis*) *botia*, Garra annandalie, *Puntius sophore*, *P. conchonius*, *Esomus dandricus*, *Danio rerio*, D. dangila, *D. devario*, *Mastacembalus pancalus*, *Xenentodon cancila*, *Clarias batrachus*, *Heteropneustes fossilis*, *Schizothorax plagiostomus*, *Channa gachua* etc. have been reported from Harpan Khola, Phewa Lake (Prajoo, 2007).

Until now the indigenous fish fauna of Nepal has not been impacted upon from exotic species. However, a decline of 42% of yield of native species (*Mystus* spp. and *Puntius* spp.) had been observed after the introduction of bighead carp – *Aristichthys nobilis*, silver carp – *Hypopthalmicthys molitrix* and grass carp – *Ctenopharyngodon idella* in Begnas Lake, Pokhara valley (Swar and Gurung, 1988). The plankton feeding fish species are considered to be eco-friendly as they are net removers of nutrients. As such these exert beneficial impact on water bodies which are often subjected to eutrophication. Pradhan and Pantha (1995) reported that fish production removed 272 kg of phosphorus and 2,048 kg of nitrogen from Lake Phewa, Pokhara. Considering the nutrient loading in the lakes, removal of nutrients using plankton feeding fish is one of the alternatives to keep the lake environment healthy and balanced. Plankton feeding exotic fish introduced in the lakes of Pokhara Valley do not breed naturally. As such, these do not exert negative impact on the environment in terms of mass propagation affecting the populations of indigenous fish species. Moreover, the effect of proliferation of the exotic African cichlid species, *Oreochromis mossambicus* in Nepalese water bodies needs to be assessed. In the mean time, farming of African catfish, *Clarias gariepinus* and rainbow trout, *Onchorhyncus mykiss* is becoming popular in Nepal. Both of these species being carnivorous, a strong preventive protocol is needed to be followed to prevent their escape into the natural waters.

Environmental aspects of reservoirs

In Nepal, lakes and reservoirs in the mid hills are used for multiple purposes such as recreation, irrigation, hydropower generation, navigation, fisheries and drinking water supply. Reservoirs trap agricultural chemicals and wastes from catchment areas adding nutrients into water. Turbidity due to suspended solids and siltation as a result of erosion from uplands is also a serious factor affecting fish communities. Hence, some fish species gradually disappear while others flourish.

River impoundment upsets the long established balances of temperature, gaseous distribution and energy flows of the flowing river system. The most noticeable change is the stratification of water temperature into epilimnion, thermocline and hypolimnion. In Indrasarobar reservoir, the temperature varied from 12-17°C during winter and 17-27°C during summer. Also during summer, the reservoir was stratified with a thermocline at 13-14 m and dissolved oxygen becoming very low in deeper layers (Pradhan and Swar, 1988).

Dams affect fish spawning, migration and the species composition of rivers. Hill stream fishes such as *Pseudoecheinus sulcatus*, *Glyptosternum* spp, *Noemacheilus* (*Acanthocobitis*) spp., *Barilias* spp., *Psilorhynchus pseudecheneis*, *Garra* spp. etc found in Kulekhani river are threatened and population have declined. Stream fish populations are currently confined to *Acrossocheilus* (*Neolissochilus*) *hexagonolepis*, *Puntius chelynoides*, *Schizothorax richardsonii* and *Tor* species. The population of previously dominant *S. richardsonii* had decreased and *A. hexagonolepis* become dominant among indigenous fish. The new biota adapted to lake habitats have established with abrupt and drastic changes in species composition but increased growth of phytoplankton, zooplanktons and zoobenthos such as nymphs, chironomids, ceratopoganid larva. Macrophyte growth is an ecological problem in shallow regions of reservoirs.

Fisheries

Fishing in lakes and reservoirs is a traditional practice in Nepal but is not well organised. Fishers use traditional gear for subsistence fishing. The capture fisheries in these waters are of artisanal nature and have no industrial fisheries potential. From the national perspective, fisheries development potential in lakes and reservoirs seems to be low due to limited area available at present. However, the potential is high at the local level since it is relatively easy

to manage and develop because of the nature of these water bodies. The potential yield per unit area from lakes and reservoirs is much higher than that of rivers. Thus, lake and reservoir fisheries can contribute significantly to local nutrition and livelihood development. With good road access and other infrastructure developed, part of the local produce could be sold in the distant markets thereby increasing the economic status of the local communities.
In view of this potential, the government has accorded due priority towards fisheries development in lakes and reservoirs through fish conservation, fisheries management, fish culture in cages and enclosures, open water stocking management, etc for enhanced production. The policy is to utilise natural productivity of these water bodies in fish production limiting to extensive culture practices. By doing so, ecological balance can be properly maintained for sustainable utilisation of the resources.

Cage fish culture in lakes and reservoirs with Chinese carps (mainly silver carp and bighead carp) was initiated with the support of FAO/UNDP during the late 1970's in Phewa, Begnas and Rupa lakes of Pokhara valley and later extended to Indrasarovar reservoir, Kulekhani during early 1980's with support from the International Development Research Centre (IDRC), Canada. In Nepal, bighead and silver carps are popular for cage culture. These fish species are stocked at low stocking densities (10-12 fingerlings/m^3). Rohu (*Labeo rohita*) is also stocked in small numbers as a biological cleaning agent in cage fish culture (Sharma, 1979). The stocking ratio of silver carp and bighead carp had been manipulated depending upon the abundance of phytoplankton and zooplankton. Silver carp was dominant in the past in Rupa and Indrasarovar while bighead carp was dominant in Begnas and Phewa lakes.

The cage fish culture system has been quite successful in terms of utilising natural productivity in fish production. However, studies are being undertaken to examine the viability of intensive culture of common carp and rainbow trout in cages with supplementary feeding. In general, nylon or polythene knotless floating cages 5 m long, 5. m wide and 2.0-2.5 m deep are mostly used for this purpose.

Polyculture of planktivorous carps in lake enclosures in Pokhara valley has been developed as a popular aquaculture activity. It has further underlined the potential role of lakes for increasing fish production. Currently, the practice is being transferred to Indrasarowar reservoir to enhance production. The activity at the moment is being managed by community federations with positive outcomes.

Stocking of fingerlings in open water is occasional and is not based on stock assessment. Also, there is no proper database system developed for planning such stocking strategies. Currently, open water stocking practice is being managed by cooperatives in Rupa, Kaski. In Jagdishpur reservoir located in Kapilvastu district, open water stocking is being managed by a group of private enterprises. However, the viability of these activities has not yet been assessed.

The fish production from cage fish culture in 1981/82 had been reported to be 10 tonnes from 3,110 m^3 of cages with an average productivity of 3.2 kg m^{-3}. The fish production from cage fish culture reached 180 tonnes from 30,000 m^3 cages in 2001/2002. This increase in cage volume by almost 10 times and fish production by 18 fold in 20 years indicats the growing popularity of the activity. The growth trend in cage volume had been gradual until 2004/2005, and it increased by almost two fold in 2005/2006. However, the productivity rate remained quite consistent at almost 6 kg m^{-3} in all these years. During 2005/2006, cage fish culture produced 480 tonnes of fish from 80,000 m^3 of cages, with an average yield of about 6 kg m^{-3}. Indrossoraber reservoir, Kulekhani constituted 54,200 m^3 of cages comprising over 67% of total cage volume in Nepalese lakes and reservoirs. The production from fish culture in lake enclosures during 2005/2006 reached 140 tonnes from an area covering 100 ha (Table 4).

In Nepal, fish yield in capture fisheries in lakes and reservoirs are reported to be about 160 kg ha^{-1} -$year^{-1}$ and 242 kg ha^{-1} $year^{-1}$, respectively. This is very low compared to reservoir fish yield in other countries. The average fish yield in Chinese reservoirs is about 370 kg ha^{-1} -$year^{-1}$ (Lorenzen, 1998). India is the second largest fish producer in reservoirs in Asia producing more than 10,000 metric tons/year (Srivastava, 1985). However, fish yield in Indian reservoirs in terms of kg ha^{-1} $year^{-1}$ is much lower (Sugunan, 1995). In Nepal, fish production from lakes and reservoirs reached 1,163 tons during 2005/2006 which was about 6% of the total fish production of 20,016 tonnes from capture fisheries in the country. The total fish production in Nepal reached 45,425 tonnes in 2005/2006, and contributed 2.75% of the Agriculture Gross Domestic Production. The per capita fish production reached 1,755 g in Nepal during 2005/2006. Fisheries and aquaculture development activities in Nepal employed about 511,000 individuals of 139,000 families and benefited 758,000 people; almost 3% of the total population during 2005/2006. Also, it has been estimated that capture fisheries employed over 83% individuals in the fisheries sector, of which women employment consisted of about 60% in 2005/2006. A preliminary analysis on employment and income generation has shown that aquaculture employed fewer people but had higher income potential compared to capture fisheries.

Fisher organisations

The cage owners in Phewa, Begnas Rupa lakes and Indrasarovar reservoir have developed a group/community concept in managing the enterprise. The organisational modality developed does not follow the prototype concept since it is entirely dependent upon local conditions. However, each organisation seems to be functioning effectively. The fisher communities have been organised in an 'Association/Federation Concept' in Lakes Phewa and Begnas and Indrasarovar reservoirs. The cooperatives concept has been adopted by the fisher community of Rupa Lake for better management of the fisheries resources. This lake is small and isolated. It is basically utilised by local people for irrigation purposes. The cooperatives organisation has plans to manage the resources in a holistic and integrated manner by inducting cross-sectoral enterprises such as eco-tourism,

Table 4 : Details of area coverage and fish production from aquaculture and fisheries in Nepal.

Particulars	ADB supported project		Base year				10th Year Plan						Growth % compared with the base year	
							Accomplishment				Projected			
	Production 1981/1983		1993/1994		2001/02		2004/05		2005/06		2006/07			
	Area (ha)	t	Area (ha)	t	Area (ha)	t	Area (ha)	t	Area (ha)	t	Area (ha)	t	Area (ha)	t
Aquaculture		750		8317		17100		22480		25409		26650		56
Pond	944	740	4593	8215	5954	15516	6220	20213	6337	22545	6500	23800	9	53
Paddy cum fish culture				17	160	64	277	111	300	120	300	135	88	111
Cage culture (m^3)	3110	10	10639	56	30000	180	36000	216	80000	480	80000	480	167	167
Pen culture			4	9	100	130	100	130	100	140	100	140	0	8
Extensive fish culture in swamps and ditches			61	20	1000	1170	1400	1778	1612	2096	1612	2096	61	79
Aquaculture activities (public sector)				55		40		32		28				
Capture Fisheries	728500	2780	728500	6356	811000	17900	810610	19983	810388	20016	810388	20100	0	12
Rivers	395000	2075	395000	3950	395000	5233	395000	6951	395000	6992	395000	7031	0	34
Lakes	5000	25	5000	139	5000	780	5000	795	5000	800	5000	805	0	3
Reservoirs	1500		1500	77	1500	341	1500	356	1500	363	1500	364	0	7
Other areas (swamps and ditches)	2000	100	12500	500	11500	5003	11110	5051	10888	4976	10888	4987	-5	0
Paddy fields	325000	580	325000	1690	398000	6543	398000	6830	398000	6885	398000	6913	0	6
Total		**740**		**9960**		**35000**		**42463**		**45425**		**46750**		**34**

forestry conservation and navigation for better economic returns. Recently, open water stocking and associated fisheries production management activities have been initiated at Jagdishpur reservoir which has been constructed primarily for irrigation in Kapilvastu, western Tarai district in Nepal. The fisheries production management activities are currently being managed by a group of private entrepreneurs. The profitability of the enterprise has been assessed with encouraging outcomes.

Economic viability, marketing aspects, profitability and value addition

Extensive management of cage fish culture in lakes and reservoirs is considered easier and eco-friendly because fish in cages utilise natural food for growth. The system of extensive cage culture of planktivorous fish in lakes and reservoir is beneficial with quick return on investment compared to other agricultural practices. For this purpose, one fisher family needs at least 5 cages of 250 m^3 to make it profitable and sustainable (Swar and Pradhan, 1992). The cage culture of carps in the lakes of Pokhara valley had been found to be viable with a net benefit of Rs. 31.2/m^3 (Sharma, 1990). This technology is considered to be one of the most economical methods of fish rearing in Nepal. Extensive cage fish culture is based on natural productivity and no supplementary feeding is practiced, which consequently reduces the cost of production considerably. As such, this aquaculture system is affordable for poor and low income farmers. The future expansion of these practices will make an important contribution to improve the economic status of the communities in the mid hills.

Regarding the marketing of the product, bulk is disposed locally. With easy access to road and other infrastructure developed, the fish produced in lakes of Pokhara valley are marketed in the distant markets of Kathmandu, Chitwan and other urban centers of Nepal. The fish produced in Indrasorovar reservoir is disposed both locally and at distant urban centers. There is a substantial demand for dried fish in the local market. A solar drier plant had been installed in Indrasorovar reservoir for the use of local fisher community to make dried fish and to introduce the concept of value addition to the product for higher net returns. A fish processing plant had been already installed in Pokhara, and it is being operated with success.

Constraints to reservoir fishery development

Policy/legislation

The hydropower and irrigation projects have been accorded high national priorities for economic development in Nepal. However, there is a basic disparity in national policy regulations in terms of judicious utilisation of natural water resources. The damming of rivers for run off or reservoir schemes for hydropower and irrigation projects have overlooked the biological and socio-economic aspects. These cross-sectoral issues should be accorded equal importance by incorporating appropriate mitigation measures through holistic management approaches to maintain the biological, environmental and socio-economic aspects of the impacted area in a sustainable manner.

The importance of and need for fisheries resource conservation were realised quite early in the country. The *Aquatic Life Conservation Act 1961* – "JAL CHAR SANRAKSHAN AIN – 2017" had been adopted, but could not be implemented for some time. In 1999, the Act was amended (2055 BS). changes included important aspects such as its scope and the definition of different terms specified in the Act. The other aspects included in aquatic life conservation act are: restrictions on killing and capture methods, punishments, citizen's obligations, role and the responsibility of local authority and technical authority. However, the Act is not yet in operation because laws and regulations are yet to be approved by the government.

Ecological impacts

The damming of river for hydropower/irrigation development converts the lotic habitats of river into lentic habitats. As a result, some native fish species are threatened and gradually disappear due to the loss of spawning grounds, migratory routes, and imbalance of physio-chemical factors and energy flow mechanisms of flowing river system habitat. Nevertheless, other limnophilic species flourish. Also, many native fish species are threatened as they are driven into turbines of hydropower plants. This issue has not been considered in the basic engineering and design of the project so that mitigation measures have not been adopted. Hence appropriate mechanisms at the policy level are required to safeguard the loss of native fish species and other aquatic fauna through suitable mitigation measures to minimise the biodiversity losses.

Impacts of cross-technological activities/urbanisation

Hydropower and irrigation projects require high investment and long term service delivery for the recovery of cost. The siltation caused by continued wash down of loose soil due to haphazard agricultural practices and deforestation in the surroundings and uplands is a serious problem to reservoir hydrology, its fishery and other aquatic biological resources. The continued accumulation of mud in the reservoir bottom diminishes water storage volume and affects the cost effectiveness of hydropower production. Also, addition of wastes from urban settlements and industrial wastes have deteriorated the aquatic environment to some extent in Phewa and Begnas lakes as well as Indrasarovar reservoir. As such, holistic management approaches are required for lake and reservoir management focusing prevention of soil erosion through sound plantation management, maintenance of drainage system through proper engineering works in the surrounding hills, effective management of sewage/effluent discharge schemes.

Socio-economic aspects

Utilisation of natural water resources for development interventions can cause serious socio-economic problems. Such development activities may displace human settlements and affect livelihoods, life styles and values. Fisher communties are often the most seriously impacted and considered highly vulnerable and deprived, and mostly belong to poor classes. Providing new areas of re-settlement for these displaced communities is costly and is a highly sensitive issue. The issue should be addressed by providing appropriate alternative livelihoods and settlements to the affected communities through appropriate mitigation measures and management.

References

Aizaki, M. 1986. Trophic status and water quality of high altitude lakes in Mount Annapurna region. In: Y. Ishida (ed.). *Studies On Distribution, Adaptation and Evolution of Micro-organisms In Nepal Himalaya*. Second Report. Tokyo University Press, Tokyo.

Brehm, 1953. *Some aquatic fauna from Kalipokhari Eastern Nepal* (unpublished).

DOFD, 2006. *Country Profile – Nepal 2005/2006, Fisheries Sub-sector*, Directorate of Fisheries Development (DOFD), Kathmandu, Nepal.

Ferrow, W., Swar, D.B, 1978. Bathymetric maps from three lakes in Pokkhara valley (Nepal). *Journal of the Institute of Science and Technology*, 1: 177-188.

Gautam, G., 2003. *Study on the fish diversity and aquatic life resources of Rupa Lake, Kaski*. Dissertation submitted to the Central Department of Zoology, T.U., Kathmandu.

Gurung, T.B., Wagle, S.K., 2002. *Importance of water quality for optimizing fish yield, A review paper presented in technical seminar on information sharing in aquaculture, October 18-19, 2000) Kathmandu*. Fisheries Training Center, Janakpur Nepal.

Hamilton, F.B., 1822. *An Account of the Fishes found in the River Ganges and its branches*. Edinburgh and London, London.

Hickel, B., 1973. Limnological investigation in lakes of Pokhara Valley, Nepal. *Internationale Revue gesamten Hydrobiologie*, 58: 659 - 672.

Himalayan Power Consultant, 1889. *Feasibility report on Karnali (Chisapani) multipurpose project*, 28 Vol. Kathmandu, Nepal.

Kirkpatrick, W., 1793. *An Account of the Kingdom of Nepaul, being the Substance of Observations made During a Mission to that Country, in the Year*

1793. London: William Miller, 1811. Reprinted, New Delhi: Asian Educational Services, 1996.

Loffler, H., 1969. High altitude lakes in Mt. Everest region. *Verhandlungen der internationale Vereinigung für theoretische und angewandte Limnologie*, 17: 373-385.

NARC, 1991. *Nepal Agriculture Research Study (TA No. 1182 NEP), ANNEX No. 4 - Fisheries and Aquaculture in Nepal, M 1975-2005)*. A study Team Report Prepared for the National Agriculture Research Centre and Asian Development Bank, Lalitpur, Nepal.

Pradhan, B.R., 1982. Preliminary studies of Syarpu Daha a mid hill lake in Rukum District. Nepal, *Proceedings of the National Science and Technology Congress*. National Council of Science and Technology, Kathmandu, Nepal.

Pradhan, B.R., Swar. D.B., 1988. Limnology and Fishery Potential of the Indrasarovar Reservoir, Kulekhani, Nepal. In: De Silva, S.S. (ed.), *Proceedings of a Workshop on Reservoir Fishery Management and Development in Asia*. Interntional Development Research Center, Ottawa, Canada.

Pradhan, G.B.N., Pantha, M.B., 1995. *Nepal Country Report (Annex 11-12). Report on a Regional Study and Workshop on the Environmental Assessment and Management of Aquaculture Development*. Food and Agriculture Organization of the United Nations and Network of Aquaculture Centres in Asia-Pacific, Bangkok, Thailand.

Prajoo, N., 2007. *Study on Fish Diversity of Harpan Khola and Socio-economics of the Jalari Women of Phewa Lake*. A M.Sc. Thesis submitted to Tribhuvan University, Nepal.

Prosser, J., 1978. *Environmental Report in Gandaki River Basin Power Study*. Nepal Electricity Authority, Kathmandu, Nepal.

Sharma, B.P., 1990. *Economics of cage culture of carps in the lakes of Pokhara valley, Nepal*. Report submitted to Interntional Development Research Center Singapore.

Sharma, C.K., 1997. *A Treatise on Water Resources of Nepal*. Kathmandu, Nepal.

Sharma, R.N., 1979. Cage fish culture in Nepal. In: *International workshop on pen and cage culture of fish (11-12 Feb 1979) Tigbaun, Iloilo, Philippines*. Interntional Development Research Center and Aquaculture Department. SEAFDEC, Philippines.

Shrestha, S.B., Shrestha, T.K., Pradhan, B.R., 1979. *Reports on the study of aquatic ecology and the potential of fisheries development in Bagmati River Project*. A Report prepared for GTZ, Kathmandu, Nepal.

Srivastava, U.K. (Ed.) 1985a. *Inland Fish Marketing in India. Vol. 4A: Reservoir Fisheries*. Concept Publishing, New Delhi.

Sugunan, V.V., 1995. Reservoir fisheries of India. *FAO Fisheries Technical Paper*, 345. Food and Agriculture Organization of the United Nations, Rome.

Swar, D.B., Gurung, T.B., 1988. Introduction and cage culture of exotic carps and their impact on fish harvest in Lake Begnas, Kaski, Nepal. *Hydrobiologia*, 166: 277-283.

Swar, D.B., Pradhan, B.R., 1992. Cage fish culture in the lakes of Pokhara valley, Nepal and its impact on lake fisheries. *Asian Fisheries Science*, 5: 1-13.

Terashima, A., 1984. Three new species of the Cyprinoid genus *Schizothorax* from Lake Rara, North-Western Nepal. *Japanese Journal of Ichthyology*, 31: 122-135.

Water Resources Strategy of Nepal, 2002. Hydro Power Commission, Ministry of Water Resources, Government of Nepal, Kathmandu, Nepal.

Yadav, U.K.R., 1994. Studies on the water quality and benthic fauna of the feeding river, Palung and Streams, Charkhu, Thudo, Chitlang of the Kulekhani reservoir. In: *Proceedings of Second National Congress on Science and Technology (June 8-11, 1994)*. RONAST, Kathmandu, Nepal.

Present Status and Future Strategies for the Management of Reservoir Fisheries in Sri Lanka

Upali S. Amarasinghe[1] and D.E.M. Weerakoon[2]
1. Department of Zoology, University of Kelaniya, Kelaniya GQ 11600, Sri Lanka.
2. National Aquaculture Development Authority of Sri Lanka, 758, Baseline Road, Colombo CO 00900, Sri Lanka.

Introduction

Sri Lanka is a continental island in monsoonal Asia with rich water resources. There are 103 perennial rivers in Sri Lanka, most of which drain from the central highlands into the western, southern and eastern coasts. In addition a multitude of reservoirs on the island support rich aquatic biodiversity (Fernando and Weerawardhena, 2002). The extant reservoirs in Sri Lanka consist of ancient reservoirs that have been restored and rehabilitated, and new reservoirs constructed primarily for irrigation and/or generation of hydroelectricity.

Reservoir resources in Sri Lanka

As mentioned by Costa and De Silva (1995), the total extent of reservoirs of the country can be considered about 170,000 ha (Table 1). As such, reservoir density in Sri Lanka is about 2.7 ha per every square kilometre of the country which is perhaps the highest density of reservoirs in the world (De Silva, 1988). There are over 10,000 reservoirs in Sri Lanka but most of them are less than 100 ha in surface area. According to Panabokke (2001) these small village reservoirs that are distributed across the undulating landscape of the dry zone are not randomly located but are found to occur in the form of distinct cascades that are positioned within well-defined small watersheds or meso-catchment basins. One reservoir is about 6,000 ha, about 6 are around 3,000 ha and about 40 reservoirs are approximately 500 ha in surface area (Fernando, 2000).

The inland fishery of Sri Lanka is essentially a capture fishery in major and medium-sized perennial reservoirs of the country. Recently, attempts have been made to develop culture-based fisheries in small village reservoirs. In most of these small village reservoirs, water is retained from the inter-monsoonal rains in November – December to a peak dry season in August – October. It has been shown that these seasonal reservoirs and other small-sized perennial reservoirs where virtually no capture fisheries are practiced can be used to develop culture-based fisheries through stocking of hatchery-reared Chinese and Indian major carps and subsequent recapture after growth period of 7 - 9 months (Thayaparan, 1982; De Silva, 1988).

Table1. The estimated surface area of lentic water bodies of Sri Lanka (Source: Costa and de Silva, 1995).

Type	Number	Area (ha)	Percent
Major irrigation reservoirs (ancient)	72	70,850	41.7
Medium-scale reservoirs (ancient)	160	17,001	10.0
Minor irrigation reservoirs (ancient) including seasonal reservoirs	> 10,000	39,271	23.1
Floodplain lakes (natural)		4,049	2.4
Upland hydroelectric reservoirs (recent)	7	8,097	4.7
Mahaweli multipurpose system of reservoirs (recent)		13,650	8.0
Other		17,023	10.0
Total		**169,941**	**100.0**

Fish fauna in reservoirs of Sri Lanka

In Sri Lankan freshwaters, 85 native fish species belonging to 19 families are reported to occur (Newrkla and Duncan, 1984; Silva and Davies, 1988; Pethiyagoda, 2006; Weliange *et al*. 2008). In addition, 24 exotic species have been introduced to Sri Lankan freshwaters since late nineteenth century and three of them (*Chitala ornatus*, *Clarias batrachus* and *Pterygoplichthys multiradiatus*) are accidentally introduced exotic fish species (Amarasinghe *et al*., 2006; Shirantha and Amarasinghe, 2006). Since the introduction of the two exotics *Salmo trutta* and *Onchorynchus mykiss* during the late nineteenth century for purposes of establishment of sport fishing, several exotic species have been introduced either deliberately or accidentally into Sri Lankan freshwaters. Introduction of most exotic species during the twentieth century was to develop inland fisheries in Sri Lanka (Amarasinghe, 1998a). Possibly due to the differences in habitat preferences, reservoir fish communities are not essentially similar to the fish communities in associated rivers and streams. List of fish species reported to inhabit in the reservoirs of Sri Lanka is given in Table 2.

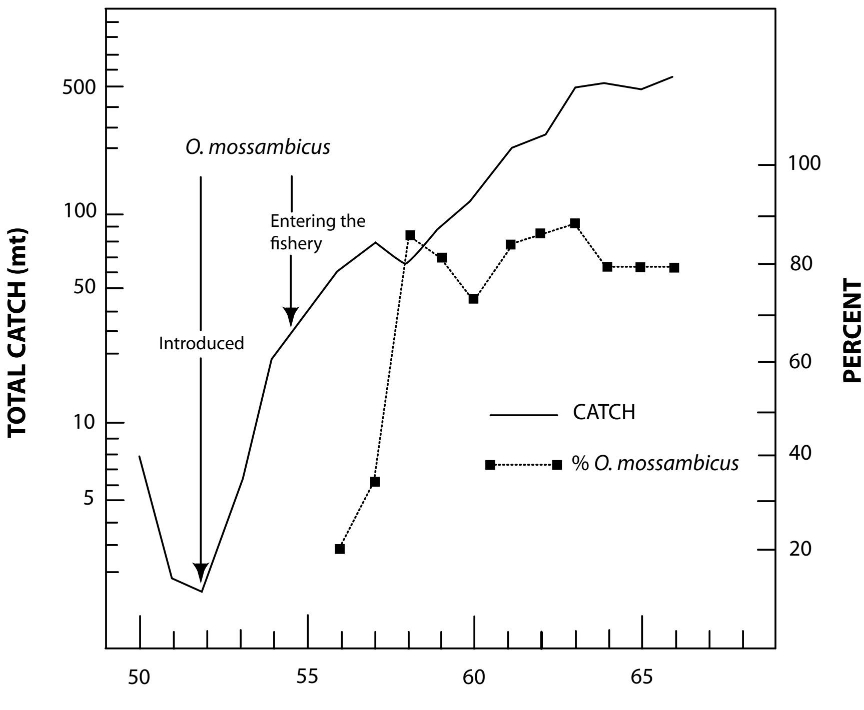
A brief history and recent trends of inland fisheries of Sri Lanka

Siriweera (1986, 1994) based on the evidence found in stone inscriptions, stated that inland fish were exploited from reservoirs even during the time immemorial. Laws were in place at that time to control fisheries and establish fishing rights (Siriweera, 1986, 1994; Ulluwishewa, 1995). However, prior to the 1950s, fish yields in Sri Lankan reservoirs were reported to be very low (Fernando, 1984, 2000). The reason for these low yields was said to be due to inability of indigenous riverine fish species to sustain high population densities in the lacustrine habitats of reservoirs (Fernando and Holcik, 1991).

A productive fishery was established in reservoirs of Sri Lanka after the introduction of the exotic cichlid species, *Oreochromis mossambicus* into country's freshwaters in 1952 (De Silva, 1988). The dramatic increase in inland fish production in Sri Lanka is best exemplified by the trends in the fishery of Parakrama Samudra reservoir during 1950s and 1960s (Figure 1).

The capture fisheries in major reservoir of Sri Lanka are characterised by the following: (a) the use of non-mechanised fiberglass canoes, approximately 6 m in length manned by two persons; (b) the gear used comprises exclusively of gillnets (6-20 net pieces per craft), ranging in mesh size from 7.5 cm to 12.7 cm, with each net piece being of a standard length and height of 60 m and 1.5 m, respectively; and (c) the predominant catch is exotic cichlid species, *O. mossambicus* and *O. niloticus*.

Figure 1. Trends in the fishery of Parakrama Samudra reservoir during 1950-1967 (Adopted from De Silva 1988).



Status of capture fisheries in reservoirs of Sri Lanka

The dramatic increase of inland fish production resulted in an elevation of reservoir fish yields from negligible levels before 1952 to a very high level of about 283 kg ha^{-1} yr^{-1} in 1980s (Fernando, 1984; De Silva, 1988). Various explanations have been presented for the dominance of *O. mossambicus*

Table 2. List of fish species reported from the reservoirs of Sri Lanka (De Silva 1988; Amarasinghe and Samarakoon, 1988; Amarasinghe, 1992; Weliange *et al*., 2008). * = Exotic.

Family/species	Max. length (cm)	Contribution to the fishery
Anabantidae		
Anabas testudineus	25.0	Not caught in major reservoirs
Anguillidae		
Anguilla bicolor bicolor	120.0	Caught in some reservoirs with baited hooks
A. nebulosa nebulosa	120.0	Caught in some reservoirs using baited hooks
Bagridae		
Ompok bimaculatus	45.0	Low contribution to landings
Wallago attu	240.0	Rarely caught in some reservoirs
Channidae		
Channa striata	100.0	Caught in small perennial reservoirs
Cichlidae		
Etroplus maculates	8.0	Not caught in commercial fisheries
E. suratensis	28.0	Low contribution to landings
*Oreochromis mossambicus**	42.0	Major species in the reservoir fishery
*O. niloticus**	46.0	Major species in the reservoir fishery
*Tilapia rendalli**	34.0	Caught in some reservoirs during high water
Clariidae		
*Clarias batrachus**	47.0	Accidentally introduced through ornamental fisheries industry; no commercial fishery
C. brachysoma	50.0	Widely distributed but not abundant
Clupeidae		
Ehirava fluviatilis	5.6	Not caught in commercial fisheries
Cobitidae		
Lepidocephalichthys thermalis	8.0	Not caught in commercial fisheries
Cyprinidae		
Amblypharyngodon melettinus	8.0	Very abundant but no commercial catch
*Aristichthys nobilis**	112.0	Hatchery reared fingerlings are stocked in small village reservoirs
*Catla catla**	182.0	Hatchery reared fingerlings are stocked in small village reservoirs; Some evidence of naturally breeding populations
Chela laubuca	17.0	Not caught in commercial fisheries
*Cirrhinus mrigala (=cirrhosus)**	75.0	Hatchery reared fingerlings are stocked in small village reservoirs
*Ctenopharyngodon idella**	75.0	Hatchery reared fingerlings are stocked in small village reservoirs
Cyprinus carpio	60.0	Hatchery reared fingerlings are stocked in small village reservoirs; Some evidence on naturally breeding populations
Danio (= Devario) malabaricus	12.0	Not caught in commercial fisheries
Esomus danricus	13.0	Not caught in commercial fisheries

Family/species	Max. length (cm)	Contribution to the fishery
Garra ceylonensis	15.0	Not caught in commercial fisheries
*Hypophthalmichthys molitrix**	105.0	Hatchery reared fingerlings are stocked in small village reservoirs
Labeo dussumieri	35.0	High catches during rainy seasons in some reservoirs
*L. rohita**	75.0	Hatchery reared fingerlings are stocked in small village reservoirs; Some evidence on naturally breeding populations
Puntius bimaculatus	7.0	Not caught in commercial fisheries
P. chola	15.0	Very abundant but not caught in commercial fisheries
P. dorsalis	25.0	Abundant but not caught in commercial fisheries
P. filamentosus	18.0	Very abundant but not caught in commercial fisheries
P. sarana	30.0	High catches during rainy seasons in some reservoirs
P. vittatus	5.0	Not caught in commercial fisheries
Rasbora caverii	10.0	Not caught in commercial fisheries
R. daniconius	15.0	Abundant but not caught in commercial fisheries
Tor khudree	50.0	Rarely caught in some reservoirs
Gobiidae		
Glossogobius giuris	35.0	Low contribution to landings
Hemiramphidae		
Hyporhamphus limbatus	25.0	Small-scale fisheries exist in some reservoirs
Heteropneustidae		
Heteropneustes fossilis	30.0	Not caught in commercial fisheries
Loricariidae		
*Pterygoplichthys multiradiatus**	50.0	Accidentally introduced through ornamental fisheries industry; Considered as a nuisance species in some reservoirs; No consumer preference.
Mastacembelidae		
Mastacembelus armatus	90.0	Not caught in commercial fisheries
Notopteridae		
*Chitala ornata**	100.0	Accidentally introduced through ornamental fisheries industry; No commercial scale fishery
Osphronemidae		
*Osphronemus goramy**	30.0	Not abundant
*Trichogaster pectoralis**	25.0	Not abundant
Siluridae		
Mystus keletius	18.0	Not caught in commercial fisheries
M. vittatus	10.0	Not caught in commercial fisheries

in Sri Lankan reservoirs and its high contribution to fish landings. Fernando and Indrasena (1969) suggested that due to the extensive availability of shallow littoral zones in Sri Lankan reservoirs, reproductive performance of *O. mossambicus* is high. Fernando and Holcik (1991) stated that high yields in reservoirs of Sri Lanka are due to ability of exotic cichlid species to colonise their lacustrine habitats, which the indigenous fish fauna, lacking lacustrine species and entirely comprising of riverine and marsh-dwelling fish species, cannot sustain dense populations in lacustrine habitats. Costa and Abeyasiri (1978) mentioned that as *O. mossambicus* is able to digest the abundant phytoplankton group, blue-green algae, which is not preferred by indigenous fish species, the introduced *O. mossambicus* has occupied a vacant niche in Sri Lankan reservoirs. De Silva (1985) has shown that due to the ability of *O. mossambicus* to change its dietary habits from season to season depending on the availability, this species has successfully colonised reservoirs of Sri Lanka.

However, a recent study indicates that at present, *O. mossambicus* is not the most dominant fish species in reservoirs of Sri Lanka (Table 3). In most reservoirs, *O. niloticus* is also equally dominant. Chandrasoma (1986) and Amarasinghe (1997) have also reported similar trends in some reservoirs of Sri Lanka.

Table 3. Percentage species composition (by weight) of landings in eleven reservoirs of Sri Lanka. Om - *O. mossambicus*; On - *O. niloticus*; Es - *Etroplus suratensis*; Ld - *Labeo. dussumieri*; EC - Exotic carps. Others include, *Ompok bimaculatus*, *Puntius sarana*, *P. dorsalis*, *Anguilla bicolor*, *A. nebulosa*, *Ophicephalus striatus*. Exotic carps landed are *L. rohita*, *Catla catla*, *Cirrhinus mrigala*, *Cyprinus. carpio* and *Hypophthalmicthys molitrix* (Data from Nissanka, 2001).

Reservoir	Om	On	Es	Ld	EC	Others
Badagiriya	27.36	43.24	<0.10	4.52	21.08	3.20
Chandrikawewa	16.96	35.17	0.64	3.35	36.75	7.01
Kaudulla	0.03	91.54	0.76	0.71	3.66	2.92
Kiriibbanwewa	2.65	87.45	<0.10	<0.10	<0.10	7.28
Mahawilachchiya	40.44	56.43	2.97	<0.10	<0.10	<0.10
Minneriya	6.44	89.27	0.81	0.69	<0.10	2.68
Muthukandiya	55.12	38.10	<0.10	0.92	3.79	1.98
Nachchaduwa	20.82	69.27	4.87	<0.10	<0.10	4.80
Nuwarawewa	35.83	48.42	4.63	<0.10	4.50	6.30
Parakrama Samudra	19.26	48.34	5.81	<0.10	11.70	9.49
Udawalawe	16.53	31.14	<0.10	24.52	19.34	5.75

Non-exploited fishery resources in Sri Lankan reservoirs

In the reservoir fishery of Sri Lanka, two exotic species, *O. mossambicus* and *O. niloticus* contribute the major portion of landings (over 90%) despite there being over 38 indigenous fish species present, 50% of which are cyprinids (Fernando and Indrasena, 1969; Fernando, 1984). These indigenous fish species remain unexploited because of poor consumer acceptability. Also gillnet mesh size restrictions targeting tilapias prevent catching these small sized cyprinids.

Small sized cyprinids are however, abundant in Sri Lankan reservoirs (Fernando, 1967; Schiemer and Hofer, 1983). Several studies have indicated that these small cyprinids could be exploited using small-mesh (15-52 mm stretched mesh size) gillnets without catching juvenile cichlids (Amarasinghe, 1985, 1990; De Silva and Sirisena, 1987, 1989; Pet and Piet, 1993). Juvenile *O. mossambicus* and *O. niloticus* are only found in shallow (<1.5 m), littoral areas of reservoirs and their adult counterparts, which are targeted by the fisheries, are found in deeper water. As such, small cyprinids can be differentially exploited in deeper, limnetic areas of reservoirs using small-mesh (18-52 mm) gillnets (Amarasinghe, 1985, 1990; De Silva and Sirisena, 1987). Pet *et al.* (1996) and Piet and Vijverberg (1998) have shown that fish producing capacities in Sri Lankan reservoirs can be increased by differentially exploiting small cyprinids. Moreau *et al.* (2001) and Villanueva *et al.* (in press) demonstrated through mass balance modelling approaches that exploitation of small cyprinids in Sri Lankan reservoirs is not detrimental but beneficial to the existing fishery based on cichlids. Amarasinghe (1990) and Amarasinghe *et al.* (2002a) have shown that these small cyprinid species (i.e. *Amblypharyngodon melettinus*, *Puntius chola*, *P. dorsalis* and *P. filamentosus*) can be utilised to make fishmeal or dried fish.

Fishery resource evaluation in Sri Lankan reservoirs

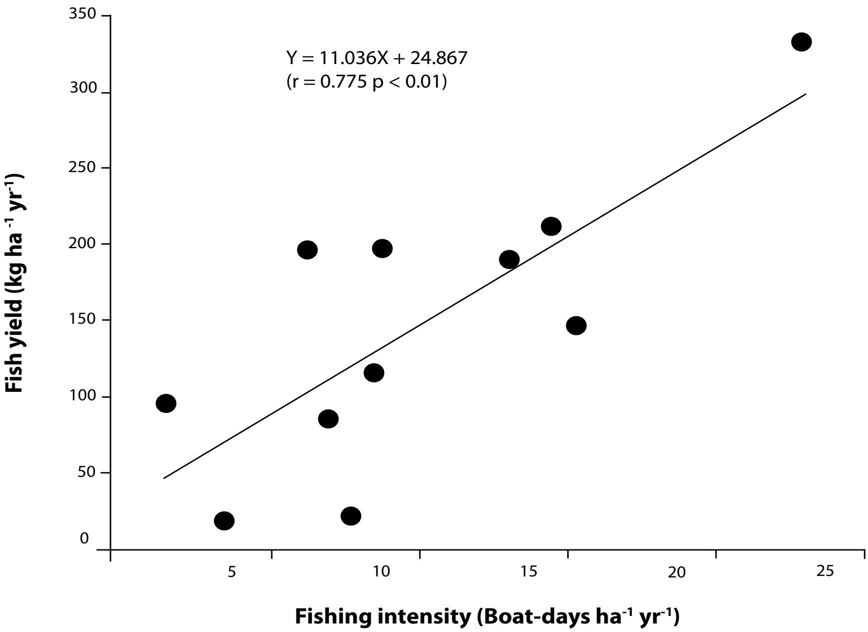
As the reservoir fishery of Sri Lanka can be treated as a “common pool resource” or “open access resource” in terms of exploitation pattern, the fisheries of individual reservoirs are usually stabilised at the level of zero economic revenue (i.e., where the revenue from the fishery is balanced with the cost of fishing). The relationship between the fish yield (kg ha^{-1} yr^{-1}) and fishing intensity (boat-days ha^{-1} yr^{-1}) of individual reservoirs (Figure 2) can therefore be used to determin the the number of boats to be employed in a given reservoir, provided an estimate of fish production potential is available.

Empirical approaches for stock assessment are particularly useful for situations where reliable data for stock assessment using standard methods are not available as is the case for most Sri Lankan reservoirs. Wijeyaratne and Amarasinghe (1987) showed that maximum sustainable yield (MSY) in several reservoirs was correlated with the morphoedaphic index (MEI = conductivity in µS cm^{-1}/mean depth in m) as described by the following equation.

$$\text{Ln MSY} = 0.9005 \text{ Ln MEI} + 1.922$$

Amarasinghe et al. (2002b) have shown the robustness of yield predictive models based on catchment features of Sri Lankan reservoirs, which were quantified by geographical information systems (GIS). In these models, the ratio of catchment land use patterns to the reservoir area or reservoir capacity are used as predictor variables of fish yield. Of the various reservoir catchment land-use patterns, forest cover and shrub cover either singly or in combination had the significant influences on fish yield. These relationships are given in Table 4 and are graphically shown in Figure 3.

Figure 2. Relationship between fish yield and fishing intensity in reservoirs of Sri Lanka (adapted from Amarasinghe, 2003).



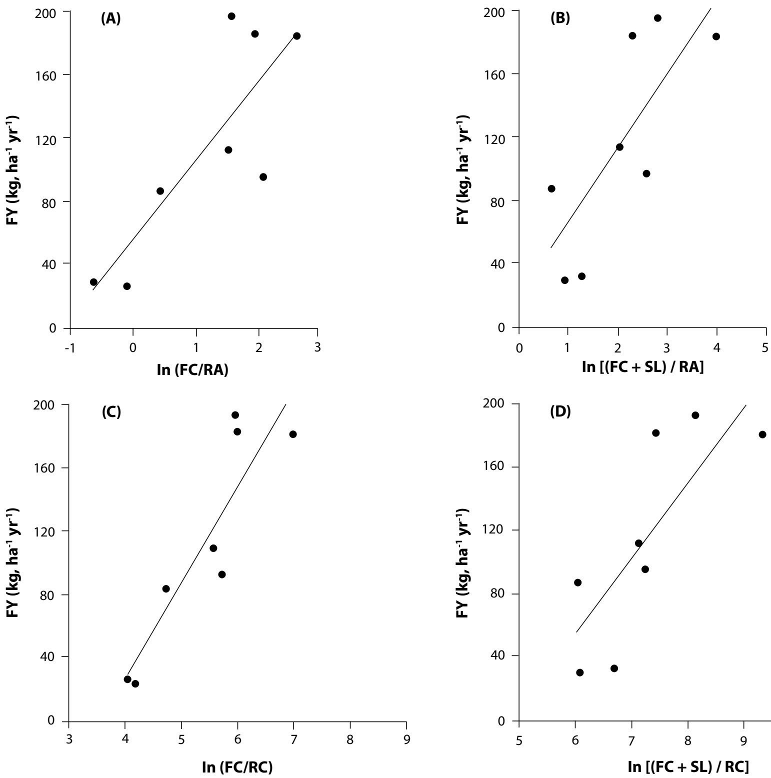
Amarasinghe *et al*. (2002b) have shown by comparing actual fish yields in several Sri Lankan reservoirs with the fish yields predicted by these models that the predictive power of these models is very high. As indicated by Meaden and Kapetsky (1991), GIS can be used as an effective means for data gathering and processing for a wide range of planning and management procedures. Using the models presented in Table 2, extents of different land-use types in catchment areas of reservoirs that can be determined from GIS methodologies, and area and capacity of individual reservoirs, which can be obtained from the Irrigation Department, it might be possible to predict fish yields of individual reservoirs with close accuracy. Also using the relationship between FI and FY presented in Figure 2, it is possible to determine the FI corresponding to fish yield predicted by the above models. As such, the empirical models based on GIS and relationship between FY and FI in Sri Lankan reservoirs are useful for determining fish yields and fishing intensities of individual reservoirs. Recently developed length-based stock assessment procedures (Pauly and Morgan, 1987; Gayanilo *et al*., 1996) offer choice of the most appropriate method for assessment of tropical fish stocks using dynamic pool models. Amarasinghe (1987, 2002), Amarasinghe *et al*. (1989) and Amarasinghe and De Silva (1992a) have employed dynamic pool models to determine the optimal fishing strategies for *O. mossambicus* and *O. niloticus* fisheries in several Sri Lankan reservoirs.

These analyses indicated that the optimal size of first capture of the two cichlid species is about 20 cm total length. Gillnet selectivity studies (Amarasinghe, 1988; Amarasinghe and De Silva, 1994) indicate that the desirable mesh size corresponding to this optimal size at first capture of cichlids in Sri Lankan reservoirs is 8.5 cm.

Table 4. Relationships between fish yield (FY in kg ha^{-1} yr^{-1}) and ratios of different catchment land-uses to reservoir area (RA) and reservoir capacity (RC). FC - Extent of forest cover; SL- Extent of shrub land. All extents are expressed in km^2. R^2 = Coefficient of determination. (Sources: Nissanka, 2001; Amarasinghe *et al.*, 2002b).

Relationship	R^2
FY = 64.931 + 43.32 ln (FC/RA)	0.693
FY = 16.558 + 47.124 ln [(FC + SL)/RA]	0.602
FY = -154.42 + 41.283 ln (FC/RC)	0.810
FY = - 170.7 + 38.265 ln [(FC + SL)/RC]	0.634

Figure 3. Relationships between fish yield (FYFSL) and ratios of different catchment land-use types to reservoir area and reservoir capacity. Abbreviations are as stated in Table 4.



Strategies for management of capture fisheries in perennial reservoirs

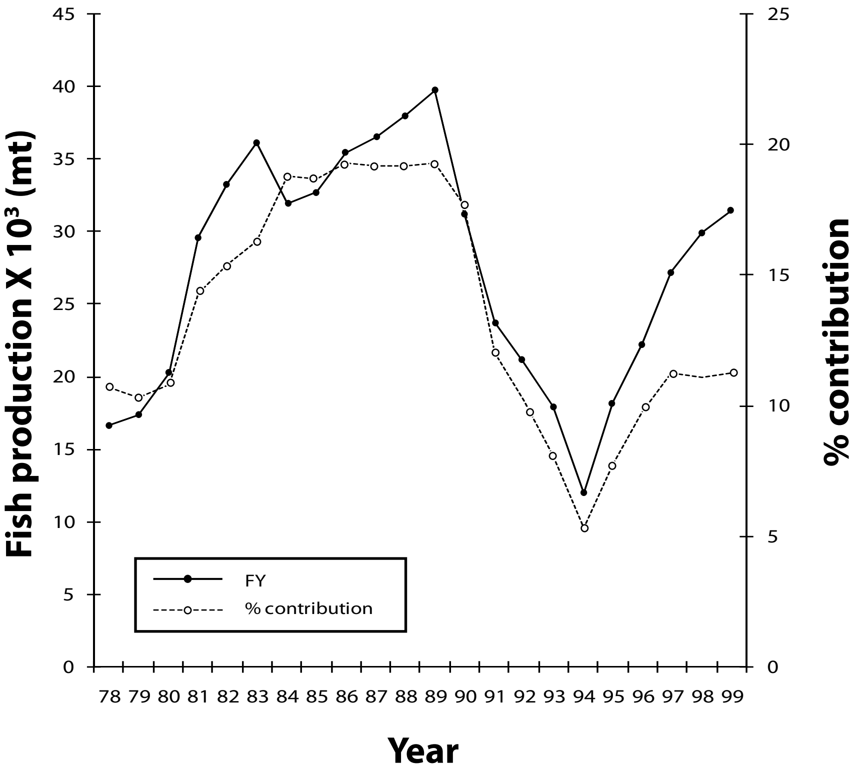
During 1979-1989 period, the government of Sri Lanka took steps to develop the capture fisheries in reservoirs of Sri Lanka by providing fishers with fibre-glass canoes and gillnets under a subsidy scheme. De Silva (1988) has shown that as a result of this subsidy scheme, fishing effort in reservoir increased considerably. The fisheries authorities have also imposed fisheries regulations to control fishing effort and size of fish landed. Use of mechanised boats and any kind of shore seine nets are forbidden in perennial reservoirs and the minimum permissible mesh size for the gillnet fishery is 8.4 cm. However, gillnets of mesh sizes smaller than minimum permissible size (<8.4 cm) and beach seine, which are also illegal are operated in some reservoirs sporadically (Amarasinghe and De Silva, 1992b). Amarasinghe and Pitcher (1986) and Amarasinghe and De Silva (1992b) have reported that some fishers increase efficiency of gillnetting by beating water with wooden poles or weighted ropes to drive fishes towards gillnets. Fish production statistics corresponding to these fishing methods should also be collected depending on the magnitude of operation.

During the early 1980s, fisheries cooperative societies (FCS) were functioning effectively because fishers in inland reservoirs had to become members of the FCS in order to be eligible for receiving boats and gillnets under the state-sponsored subsidy scheme. As FCS were well-functioning, fishers tended to arrive at collective agreements regarding resource exploitation such as complete curtailing of beach seining and increasing the minimum mesh size of gillnets up to 10.2 cm. This resulted in a considerable increase in inland fish production in the country with a reported peak of 39,300 MT in 1989 (Amarasinghe and De Silva, 1999). As a result of discontinuation of state support for inland fisheries development during 1990-1994 period, inland fish production declined markedly (Amarasinghe and De Silva, 1999) as a result of interruption of government funding for monitoring and stocking programs. Consequently, fishers began using smaller meshed (<7.5 cm) gillnets that resulted in “growth overfishing” of the cichlid species, which are dominant in the fishery. However, inland fisheries have nearly fully recovered since the state restored its support in the mid-1990s. Trends in Sri Lanka’s inland fish production from 1978-1999 are shown in Figure 4.

The available evidence suggests that in the absence of state sponsored monitoring procedures or centralised management systems, reservoir fisheries cannot be managed under the prevailing socio-economic milieu. Amarasinghe and De Silva (1999) reported management systems in two reservoirs namely Maduru Oya and Muthukandiya reservoirs, where fishing communities were also actively involved in making decisions for management of the fisheries. In both reservoirs, there is well-functioning FCS. Fishers arrive at collective decisions on fisheries management and environmental protection through the FCS. This co-management procedure in which the centralised administration authority (i.e., Ministry of Fisheries) and fishing community share the responsibilities of making decisions for fishery resource management (Berkes, 1994; Pomeroy, 1995;

Sen and Raajaer-Nielsen, 1996) has been useful for preventing over-exploitation of fishery resources even during the period of non-existence of state-sponsored monitoring procedures from 1990 to 1994 (Amarasinghe and De Silva, 1999). In Muthukandiya reservoir, the FCS collects one Sri Lankan Rupee per kilogram of fish landed from the fishers to provide a welfare fund for the society. The FCS maintains a receipt book and issues receipts to each fisher on a daily basis for the money collected. As such, based on these records on accumulation of welfare fund, daily data on weight of fish landed by individual fishers can be collected. Through this procedure, total enumeration of fish production is possible in Muthukandiya reservoir. A similar community-based management system is in operation in Senanayaka Samudra (7,680 ha), the largest reservoir in Sri Lanka, where fishing trips are also regulated by the fisheries co-operative society (Dr. M. van der Knapp, pers. com.). Nathanael and Edirisinghe (2002) have also shown that co-management strategies could be introduced to the fishery of Victoria reservoir in Sri Lanka.

Figure 4. Trends in the inland fish production in Sri Lanka from 1978-1999. Percent contribution of the inland fishery to the total fish production is also indicated here (modified after Amarasinghe, 2003)



Fish stocking in perennial reservoirs: How effective?

Stocking of fish fingerlings is a commonly practised strategy to mitigate loss of stocks, enhance recreational or commercial catches, restore fisheries or create new fisheries (Cowx, 1994). In Sri Lankan reservoirs, stocking of fish fingerlings is carried out to enhance commercial catches. De Silva (1987) reviewed the stocking practices in inland reservoirs of Sri Lanka and recognised two phases.

- First phase: stocking with giant gourami, *Osphronemus goramy* commencing in the 1940s followed by *O. mossambicus* in 1950s and *O. niloticus* in mid 1970s.
- Second phase: stocking with Chinese major carps beginning in the late 1970s followed by Indian major carps in the early 1980s.

Chandrasoma (1992) reported that in three reservoirs namely, Giritale (308 ha), Kandalama (777 ha) and Udawalawe (3,374 ha), *L. rohita* that was intensively stocked in 1980s produced high yields. However, stocking of exotic carps did not result in high yields in majority of reservoirs (De Silva, 1988; Amarasinghe, 1998b). Fish yields of exotic carp species showed negative curvilinear relationship with the reservoir area indicating that high fish yields through stocking can only be achieved in small (<800 ha) reservoirs (Amarasinghe, 1998b). Such negative curvilinear relationships between yields of stocked fish and reservoir area are evident in reservoir fisheries in many parts of the world such as Mexico, China and India (De Silva *et al.*, 1992; Sugunan, 1995; Welcomme and Bartley, 1998). As the number of fingerlings needed to ensure high recovery rates in larger reservoir is too high, there is a general tendency to stock fish at lower densities into larger reservoirs (Welcomme and Bartley, 1998). Also, competition and predation will be greater in larger water bodies and therefore, survival rates of stocked fish will be reduced resulting in low recovery rates (Welcomme and Bartley, 1998).

In Sri Lankan reservoirs, early stocking regimes were arbitrary and achieved poor results (De Silva, 1987, 1988). The stocking in major perennial reservoirs of Sri Lanka has been less successful, as they are managed mainly for self-producing tilapias (Amarasinghe, 1998b). Recently, FCS in some reservoirs such as Chandrikawewa and Urusitawewa have started stocking of fish fingerlings using the funds raised in the FCS. The outcomes of these stocking regimes are however, needed to be evaluated.

Exotic carps in capture fisheries in perennial reservoirs

In Udawalawe reservoir in the Walawe river basin, fingerlings of Chinese and Indian major carps were stocked intensively in 1980s because this reservoir is situated in close proximity to a state-owned fish breeding station. In this reservoir, *O. mossambicus* and *O. niloticus* formed nearly 25% of the total landings whereas the contribution of Indian major carps (*C. catla*, *C. mrigala* and *L. rohita*) and an indigenous cyprinid species, *L. dussumieri* to the landings was about 70% (Sricharoendham *et al.*, 2008). The catch per unit effort (CPUE) expressed as kg per boat-day, in Udawalawe reservoirs was shown to be influenced by lunar phase and rainfall (Sricharoendham *et al.*, 2008). During the full-moon phase the majority of boats had lower CPUE whereas peak CPUE was reported during rainy seasons with very high proportion of *C. catla* (over 95%) in the landings. According to the information gathered from fishers, egg masses of Indian carps attached to submerged macrophytes could be observed in the inflow areas of the reservoir. This evidence suggests that self-reproducing populations of Indian major carps have been established in the Walawe river basin. Studies on the reproductive biology of Indian major carps in Sri Lankan inland waters are therefore necessary for defining reservoir fisheries management strategies.

Strategies for the management of culture-based fisheries in village reservoirs

In culture-based fisheries, artificially propagated seed stocks are released into water bodies not primarily and traditionally used for fish production, and recaptured upon reaching a desirable size (Lorenzen, 2001). De Silva (2003) mentioned that as a rule, culture-based fisheries involve ownership either singly, as in the case of Vietnam where farmers lease out small reservoirs (Nguyen *et al*., 2001), or collectively, in the form of a cooperative, such as the case in oxbow lakes in Bangladesh (Middendrop and Balarin, 1999).

The seasonal reservoirs are highly productive due to the cattle manure accumulated in the draw-down areas from cattle grazing during dry season and residues of terrestrial vegetation. Small puddles in most seasonal reservoirs do not dry up completely so that they can harbour some of the indigenous carnivorous fish species with accessory respiratory organs such as snakehead (*Channa* spp.), climbing perch (*Anabas testudineus*), catfishes (*Macrones* spp.). These indigenous species, although harvested in some reservoirs, do not produce high yields. The potential of small village reservoirs for the development of culture-based fisheries was first pointed out by Mendis (1965). Accordingly, attempts were made in 1960s to utilise these seasonal reservoirs for the development of culture-based fisheries (Indrasena, 1965). Indrasena (1965) reported that in 1960s, some seasonal reservoirs were stocked with *O. mossambicus* fingerlings of 7.5-10.0 cm and that during 8-9 months of water retention period, they grew upto 25-30 cm in size.

Fernando and Ellepola (1969) reported that in February-March 1963, eight small reservoirs in the north-central province of Sri Lanka were stocked with *Chanos chanos* and *O. mossambicus*, which were harvested in September 1963. They also reported their observations in Dalukanawewa during fishing season in July-August 1964. Fish harvests from three of these reservoirs, as estimated from the values indicated by Fernando and Ellepola (1969), are given in Table 5. Mendis (1977) has estimated the culture-based fisheries production potential of the small village reservoirs as 13,000 tonnes on the basis of mean fish yield of the mean fish yield of 330 kg ha^{-1} yr^{-1}.

Table 5. Fish harvests from three seasonal reservoirs in the north-central province of Sri Lanka in early 1960s. *Oreochromis mossambicus* constituted practically the whole catch (Source: Fernando and Ellepola, 1969). Effective area of a seasonal reservoir is considered as 50% of the extent at fully supply level (FSL). The fish yield is estimated for effective area of each reservoir.

Reservoir	Culture period	Extent at FSL (ha)	Effective area (ha)	Total catch (kg)	Yield (kg ha^{-1} yr^{-1})
Timbirigaswewa	1963	12	6	1,587	264.5
Moragaswewa	1963	41	20.5	3,175	154.9
Dalukanawewa	1963	12	6	1,587	264.5
Dalukanawewa	1964	12	6	2,268	378.0

Based on the recommendations by Rosenthal (1979) and Oglesby (1981), a programme has been implemented to formulate a suitable strategy for the development of culture-based fisheries in seasonal reservoirs of Sri Lanka (Thayaparan, 1982). De Silva (1988) estimated fish yields of some seasonal reservoirs, mean survival rates and mean weight at harvesting of the stocked species in seasonal reservoirs, based on the data reported by Chakrabarty and Samaranayake (1983). These estimates indicate that fish yields in a culture cycle have varied considerably from 18 kg ha^{-1} to 1961 kg ha^{-1} (Table 6). The highest survival was reported for *O. mossambicus* whereas fast growth rates were observed for *Cyprinus carpio*, *C. idella* and *A. nobilis* (Table 7). This experimental project was funded by FAO/UNDP (FAO/UNDP, 1980). As these studies have shown that there is a high potential for the development of culture-based fisheries in seasonal reservoirs, Asian Development Bank financed a project on aquaculture development in Sri Lanka, the main activity of which was the utilisation of seasonal reservoirs for culture-based fisheries development (De Silva, 1988). This project commenced in 1984 and it also involved the strengthening of 6 fish breeding centres and 8 fingerling-rearing centres, which were owned by the Ministry of Fisheries (Thayaparan, 1982).

The culture-based fisheries development trials were carried out in seasonal reservoirs in 1980s with rural community participation. Fingerlings of common carp, Chinese and Indian major carps of 5-8 cm size, produced in the fish breeding stations, were stocked in the reservoirs. At the end of the culture period of 7-10 months, fish stocked were harvested by the rural farmers using encircling nets. Chandrasoma and Kumarasiri (1986) reported that in 15 seasonal reservoirs, fish yields ranged from 220 to 2300 kg ha^{-1} (mean 892 kg ha^{-1}) within a single growing season (Figure 5).

Species cultured

As the culture period in seasonal reservoirs is 7-9 months, the species suitable for stocking in seasonal reservoirs should reach the marketable size in 6-8 months. These species should also be able to utilise the natural food resources available in the reservoirs. In Sri Lankan indigenous fish fauna, such species are not available. Exotic tilapias are not desirable because they tend to mature early in life in small water bodies. As such, culture-based fisheries in seasonal reservoirs exclusively rely on common carp, Chinese and Indian major carps. These species have been artificially spawned successfully in Sri Lanka (Weerakoon, 1979; Balasuriya *et al.*, 1983; De Silva, 1988).

Table 6. Some details of the fish yields over four growing seasons in four seasonal reservoirs (adopted from De Silva, 1988). SD - Stocking density- No/ha; CP - Culture period; T - Tilapia; GC - Grass carp; BC - Bighead carp; CC - Common carp; LD - *L. dussumieri*.

Reservoir / Year	SD	Species (%)					CP	Yield
		T	GC	BC	CC	LD	(months)	(kg/ha)
Tunkama (4 ha)								
1979/80	6250	12	44	36	8	-	8	1961
1980/81	5410	53	-	19	28	-	8	1154
1981/82	3475	-	-	81	19	-	8	3274
1982/83	1726	Not available					4	215
Thimbirigaswewa (5.7 ha)								
1979/80	9825	50	-	-	50	-	8	195
1980/81	5000	98	-	-	2	-	8	239
1981/82	3684	33	33	33	-	-	7	18
Maduwanwela (2.5 ha)								
1980/81	3780	86	-	11	3	-	8	775
1981/82	2214	-	-	77	-	23	10	424
1982/83	2129	40	27	13	20	-	8	1676
Kudahatawewa (7 ha)								
1979/80	9143	50	-	-	50	-	8	719
1980/81	4615	10	-	-	-	-	8	841
1981/82	3000	33	33	33	-	-	7	70

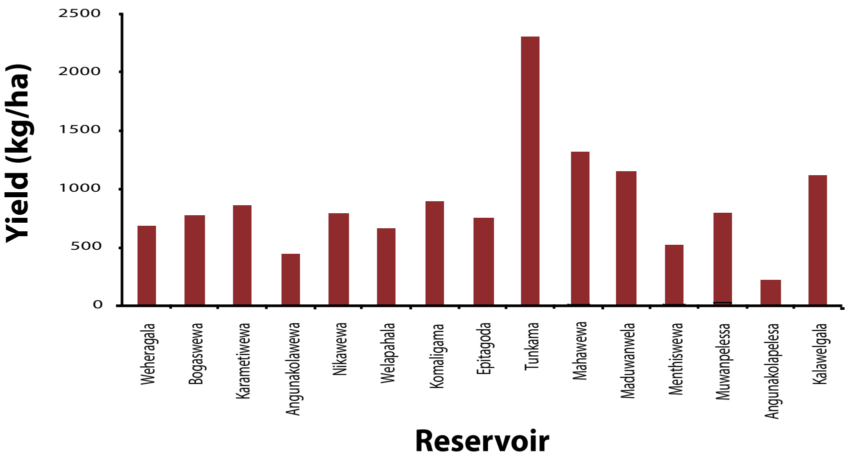
Table 7. Mean survival rates, mean weights at harvesting and yields of stocked species in seasonal reservoirs in 1979/80, 1980/81 and 1981/82. Ranges are given in parentheses.

Species	% Survival	Mean weight (kg)	Yield (kg ha^{-1})
Bighead carp	57.0 (5.0-87.3)	1.14 (0.31-2.05)	527 (62-1525)
Common carp	26.9 (0.37-50.0)	1.29 (0.46-4.55)	79 (4.2-315)
Grass carp	28.3 (0.15-30.0)	1.24 (0.3-5.4)	165 (6-764)
O. mossambicus	91.8 (79.7-100)	0.15 (0.10-0.18)	503 (412-841)
L. dussumieri	10.9 (3.9-23.3)	0.60 (0.10-1.70)	503 (9-1952)
O. niloticus	45.8 (10.6-85.7)	0.39 (0.33-0.45)	353 (25-1541)

Conditions for success of culture-based fisheries in Sri Lanka

As previous culture-based fisheries trials in seasonal reservoirs indicated that there would be a high potential for their development, it has been suggested that at a stocking density of 2000 fingerlings ha^{-1}, an average yield of 750 – 1000 kg ha^{-1} could be achieved (Charkabarty and Samaranayake, 1983, Chandrasoma and Kumarasiri, 1986; De Silva, 1988). To achieve these high yields, fingerling availability, selection of suitable seasonal reservoirs and post-stocking management are essential. It is highly unlikely that fingerlings will ever be available in sufficient quantities to stock all seasonal reservoirs in Sri Lanka. As such, it is important that wise use of the available seed stock is made through a selection of reservoirs that are suitable for developing and sustaining culture-based fisheries.

Figure 5. Fish yields within a single culture cycle (1983-1984) in 15 seasonal reservoirs. Drawn from the data presented by Chandrasoma and Kumarasiri (1986).



Pushpalatha (2001) and Pushpalatha and Amarasinghe (2007) reported case studies of rural aquaculture in Sri Lanka for the production of fish fingerling in ponds and cages. In eight earthen ponds ranging in size from 136 to 540 m^2, fry of *C. mrigala*, *C. carpio*, *L. dussumieri* and *L. rohita* were stocked and after the growing period of 62-78 days, survival rates of fingerlings were 33-86% (Table 8; Pushpalatha, 2001). Pushpalatha (2001) also reported that in 8 perennial reservoirs, fish fry were reared up to fingerling size in net cages of 4 m x 2.5 m x 2 m size, made of 4 mm mesh nets and that with the stocking density of about 5000 fry per cage, high survival rates (55-92%) were achieved within the culture period of 58-80 days (Table 9). This case study indicates that in Sri Lanka, it is possible to introduce a strategy for rearing of fish fry to fingerling size in net cages and earthen ponds. However, low-cost feed for fry rearing, subsidy schemes to cover the initial cost of cage and pond construction etc. are needed for the sustainability of this strategy. As the fingerlings should be stocked in seasonal reservoirs just after the heaviest rainy season (November-January) in the dry zone of the country, correct timing of production of fingerlings is also necessary for successful implementation of culture based fisheries in seasonal reservoirs (Figure 6). As small sized (5-8 cm) fingerlings are stocked in seasonal reservoirs, heavy mortalities were experienced (Amarasinghe, 1998b). As practised in China (Li, 1988), production of bigger fingerlings (10-14 cm) might help to minimise mortality rates of juveniles. As fingerlings are not required for stocking in seasonal reservoirs during all the seasons, they can be stocked into small perennial reservoirs (Chandrasoma, 1992). Amarasinghe (1998b) has shown that in small (<800 ha) perennial reservoirs, where the fisheries are based on cichlids are not productive, stocking of fingerlings of major carps might increase yields. Amarasinghe (1998b) however has further indicated that in planning fisheries development in small perennial reservoirs, they have to be treated

Table 8. Details of fish fingerling rearing trials in earthen ponds in two culture cycles (adopted from Pushpalatha, 2001).

Pond	Area (m^2)	Species	Fry stocked	Fingerlings produced	Culture period	Survival
1	172	*C. carpio* (cycle 1)	7,000	4,000	72 days	57%
		L. rohita (cycle 2)	7,000	4,575	67 days	65%
2	146	*C. carpio* (cycle 1)	6,000	5,000	65 days	83%
		C. mrigala (cycle 2)	6,000	4,000	69 days	66%
3	176	*L. dussumieri*	7,000	3,800	70 days	54%
4	136	*C. carpio*	6,000	2,000	72 days	33%
5	250	*C. carpio* (cycle 1)	10,000	3,800	71 days	38%
		L. dussumieri (cycle 2)	10,000	5,600	63 days	56%
6	350	*C. carpio*	10,000	5,800	68 days	58%
7	540	*L. dussumieri*	10,000	8,000	76 days	80%
8	350	*C. carpio* (cycle 1)	15,000	10,000	78 days	66%
		L. rohita (cycle 2)	8,000	4,200	62 days	53%

Table 9. Details of fish fingerling rearing trials in net cages in 8 perennial reservoirs in 2 culture cycles (adopted from Pushpalatha 2001).
Cage size: 4 m x 2.5 m x 2 m; Stocking density: 5,000 fry per cage.

Reservoir (area)	Species	Fingerlings harvested	Culture period	Survival
Bellankadawala (66 ha)	Red tilapia (cycle 1)	3,000	77 days	60%
	O. niloticus (cycle 2)	3,050	61 days	61%
Ellewewa (168 ha)	Red tilapia (cycle 1)	4,600	70 days	92%
	L. rohita (cycle 2)	4,408	65 days	88%
Giritale (360 ha)	*L. rohita* (cycle 1)	4,000	61 days	80%
	C. carpio (cycle 2)	4,100	64 days	82%
Mahakanadarawa (1,157 ha)	*C. carpio* (cycle 1)	4,000	62 days	80%
	L. dussumieri (cycle 2)	3,800	65 days	76%
Nuwarawewa (1,197 ha)	*C. carpio* (cycle 1)	4,500	72 days	90%
	L. dussumieri (cycle 2)	4,200	65 days	84%
Pimburettewa (830 ha)	Red tilapia (cycle 1)	2,800	70 days	92%
	C. carpio (cycle 2)	3,000	67 days	88%
Ranawa (60 ha)	*C. carpio* (cycle 1)	3,000	80 days	60%
	L. rohita (cycle 2)	3,500	64 days	70%
Willachchiya (972 ha)	*C. carpio* (cycle 1)	2,750	58 days	55%
	L. dussumieri (cycle 2)	3,700	63 days	74%

individually, taking into consideration the biology of the reservoir ecosystem as well as the socio-economic aspects of the rural communities living around reservoirs.

Regulatory processes

De Silva *et al*. (2005) have indicated that as the culture-based fishery activities are community dependent, the final yield from individual reservoirs will not only be dependent on biological criteria such as the natural productivity of the water bodies and the hydrological regime but also on socioeconomic factors including the degree of participation and cooperation within the community and the relative easiness of marketing the produce.

Small village reservoirs come under the jurisdiction of the Department of Agrarian Services, which establishes a village farmers' organisation in each reservoir. This farmers' organisation is responsible for day-to-day water management. In the 1980s, the liaison between the Department of Agrarian Services and the Ministry of Fisheries has improved. Since this improvement of the liaison between the Department of Agrarian Services and the Ministry of Fisheries in 1980s, a well-structured institutional link has been development between the National Aquaculture Development Authority of Sri Lanka and the Department of Agrarian Services through which the field-level coordination is considerably facilitated (Figure 7). In fact, the *Agrarian Development Act No. 46* of 2000 provides legal provision for the establishment of the major rural institution, farmers' organisation the mandate of within which constitutes the fisheries and aquaculture development whenever the farmer community decides to adopt it. In most seasonal reservoirs, farmers' organisation have set up aquaculture committees. These committees are responsible for the management of culture-based fisheries. A proportion of the profit from the culture-based fisheries is utilised for improvement of reservoir such as strengthening of the earthen bund so that there is a strong relationship between the aquaculture committee and the farmers' organisation.

The reservoir beds need to be prepared in most seasonal reservoirs prior to stocking. Removal of impediments to fishing such as submerged decaying three stumps, aquatic macrophytes etc. is necessary in order to facilitate the use of

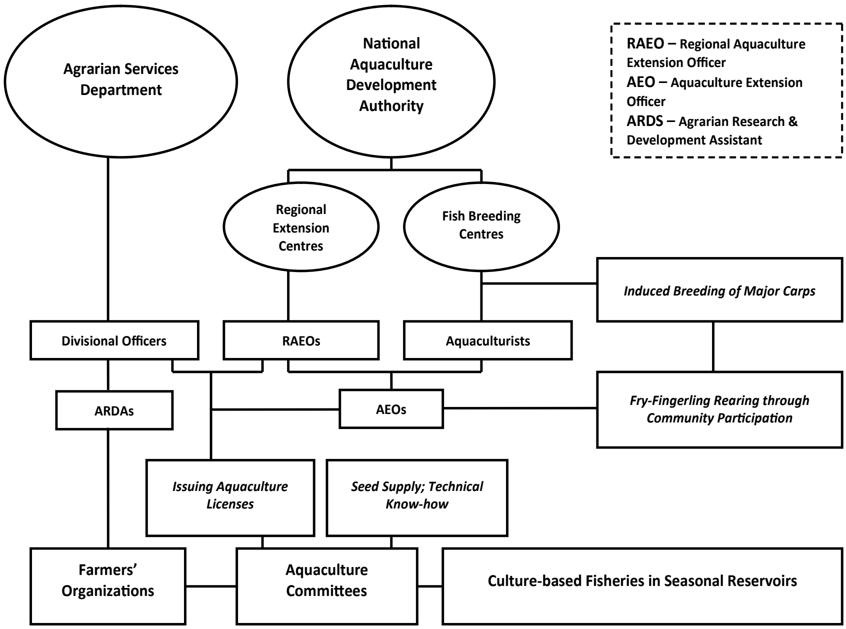
Figure 6. Correct timing of culture-based fisheries in seasonal reservoirs of Sri Lanka. Rainy reason (N, D, J) is shaded (Source: Amarasinghe, 2006).

Months																	
M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O
INDUCED BREEDING OF MAJOR CARPS		FRY REARING	FINGERLING REARING				STOCKING IN RESERVOIS					CULTURE PERIOD				HARVESTING	

seine nets for harvesting stocked fish. Members of the aquaculture committee are actively involved in these labour-intensive activities. On the other hand, we have experienced that in some reservoirs, farmers do not remove macrophytes until the onset of harvesting because presence of macrophytes in the reservoir prevents poaching of stocked fish.

The National Aquaculture Development Authority of Sri Lanka is responsible for extension activities pertaining to inland fisheries and aquaculture. Fisheries extension staff have been appointed in place of the former fisheries inspectors, whose major responsibility is technology transfer, rather than enforcement of regulation. The enabling policy, legislative environment and mechanisms to empower communities are positive aspects for realising the potential of culture-based fisheries development in village reservoirs.

Figure 7. Institutional links associated with the culture-based fisheries in village reservoirs of Sri Lanka.

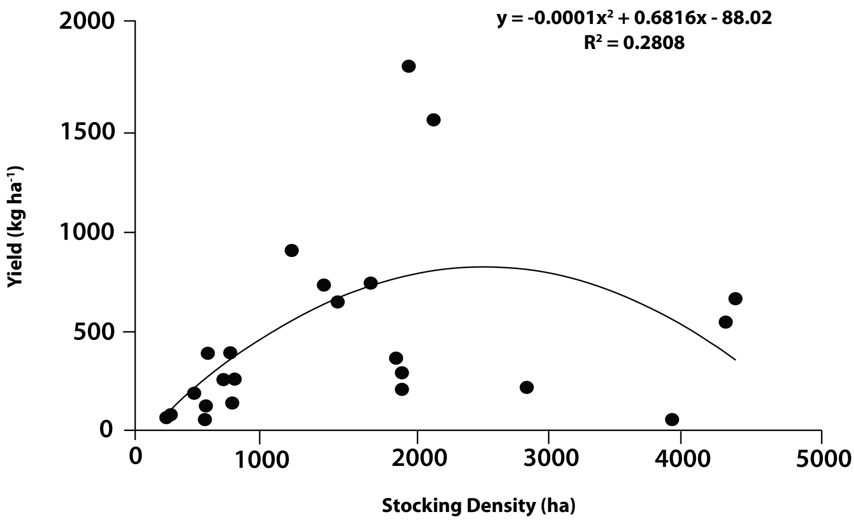


Current research on culture-based fisheries in Sri Lanka

The optimal stocking density for the culture-based fisheries in seasonal reservoirs is around 2,700 fingerlings per hectare (Figure 8). Here, the reservoir area is considered to be the effective area (i.e., 50% of the area at full supply level). Geographical information systems and remote sensing methodologies can be used to determine the reservoir area with a great precision (Wijenayake *et al.*, 2005). This is of particular importance due to the reasons that determination of the reservoir area accurately is crucial for planning culture-based fisheries and that the available information on reservoir area in the databases is largely underestimated as they were based on the maps generated from aerial photographs.

In view of the large number of seasonal reservoirs in Sri Lanka, there is a need to rank the suitability of them for development of culture-based fisheries. To develop a suitable ranking system or scale, aspects such as the physico-chemical, biological, catchment and hydrological characteristics of the water bodies, as well as socioeconomic aspects need to be taken into consideration. Accordingly, De Silva *et al.* (2005) have performed a preliminary analysis to develop a ranking system to determine the suitability of 14 non-perennial reservoirs in southern Sri Lanka. The ranking was achieved using geographical information systems and analytic hierarchy process. The latter permits a set of heterogeneous factors to be equated to a common denominator (Saaty, 1977). Thematic layers of water quality, catchment characteristics, market related aspects and socioeconomic factors corresponding to each of the seasonal reservoirs studies were evaluated using the scores that were obtained according to the weighted linear combination. The final weightings for each of the 14 reservoirs indicated that none of the reservoirs could be considered as “poor”; one reservoir was considered as “excellent”, six reservoirs were considered as “fair” and the remaining seven reservoirs were considered as “good”. The results indicated the possibility of developing such a ranking system. This research is presently being carried out more extensively in five administrative districts of Sri Lanka.

Figure 8. Relationship between fish yield and stocking density of seasonal reservoirs (Wijenayake, unpublished).



Summary and conclusions

The reservoir fishery in Sri Lanka is very productive and it provides a cheap source of animal protein for rural communities. It is one of the best, if not the best documented in tropical Asia. The stock assessment procedures employed for assessing the fisheries of Sri Lankan reservoirs enabled identification of optimal fishing strategies. Potential fish production can be estimated using catchment land-use characteristics, which can be quantified by GIS methodologies. As the fish yield and fishing intensity are linearly related in the reservoir fishery of Sri Lanka the number of boats to be employed in each reservoir could be determined using this relationship on the basis of estimated potential fish production. Length-based fish stock assessment methodologies have shown that the optimal size of first capture of the two major cichlid species is about 20 cm total length. This corresponds to the stretched gillnet mesh size of 8.5 cm as determined from gillnet selectivity studies.

Small cyprinids are abundant in perennial reservoirs of Sri Lanka. They are not exploited mainly due to poor consumer preference. Gillnet mesh size regulations targeting cichlids also make it difficult to catch small sized cyprinids. However, these small sized cyprinids can be differentially exploited without exploiting juvenile cichlids. Due to high fishery potential of these cyprinids, a subsidiary gillnet fishery can be introduced to exploit small cyprinids in reservoirs.

Except in a few reservoirs where fingerlings of Indian major carps were intensively stocked in 1980s, stocked exotic carps did not result in high yields in majority of reservoirs. There has been a recent tendency that FCS in some reservoirs stock fish fingerlings using the funds raised for the purpose. The outcomes of such stocking regimes need to be evaluated.

In Udawalawe reservoir, Indian major carps (mainly *Catla catla*) and indigenous *Labeo dussumieri* form a significant portion of the landings especially during the rainy seasons. According to the information gathered from fishers, egg masses of Indian carps attached to submerged macrophytes could be observed in the inflow areas of the reservoir. This evidence suggests that self-reproducing populations of Indian major carps have been established in the Walawe river basin. Studies on the reproductive biology of Indian major carps in Sri Lankan inland waters are therefore necessary for defining reservoir fisheries management strategies.

The extensive availability (>39,000 ha) of non-perennial reservoirs in the country which usually dry-up completely during July-September and fill during inter-monsoonal rains in December-January, permits development of culture-based fisheries. Due to high yields, culture-based fisheries in seasonal reservoirs provide a means of increasing food supply in the rural areas of Sri Lanka. As such, they could benefit the poor sectors of the rural communities significantly. The culture-based fisheries in seasonal reservoirs of Sri Lanka have little impact on the environment because they are dependant on the existing water bodies and do not involve supplementary feeding. It is a fact that there are environmental concerns with regard to intensification of aquaculture. Naylor *et al*. (2000) highlighted that use of fishmeal in aquafeeds would bring about detrimental effects on capture fisheries. Also there has been an increasing emphasis on the need of fisheries management in an ecosystem context because of the fact that the fisheries have a direct impact on the ecosystem, which is also impacted by other human activities (Garcia *et al*., 2003). The culture-based fisheries in seasonal reservoirs of Sri Lanka however, involve minimal external inputs especially due to the reason that supplementary feeds are not used. Also, being water bodies which completely dry-up during some months of the year, seasonal reservoirs do not harbour rich indigenous fish communities. On the other hand, under the inland fisheries development plan in Sri Lanka, net cage culture of fish fry to fingerling in perennial reservoirs is promoted. It is expected that this aquaculture strategy will produce part of the fingerling requirement for furthering the development of culture-based fisheries in seasonal reservoirs.

For the management of reservoir fishery of Sri Lanka, it is imperative that fishing communities be made active partners in decision the making processes. Some evidence is found from reservoirs of Sri Lanka that scientific information can also be collected through the active participation of fishing communities, as reported by Ticheler *et al*. (1998) and Neis *et al*. (1999) for comparable fisheries in other parts of the world. A co-management procedure in which the centralised administration authority (i.e., Ministry of Fisheries) and fishing community share the responsibilities of making decisions for fishery resource management (Berkes, 1994; Pomeroy, 1995; Sen and Raajaer-Nielsen, 1996) should be introduced for effective management of the reservoir fishery of Sri Lanka.

References

Amarasinghe, U.S., 1985. Studies on the exploitation of minor cyprinids in Parakrama Samudra, a man-made lake in Sri Lanka, using gillnets. *Journal of the National Aquatic Resources Agency (Sri Lanka)*, 32: 11-23.

Amarasinghe, U.S., 1987. Status of the fishery of Pimburettewa wewa, a man-made lake in Sri Lanka. *Aquaculture and Fisheries Management*, 18: 375-385.

Amarasinghe, U.S., 1988. Empirical determination of a desirable mesh size for the gillnet fishery of *Oreochromis mossambicus* (Peters) in a man-made lake in Sri Lanka. *Asian Fisheries Science*, 2: 59-69.

Amarasinghe, U.S., 1990. Minor cyprinid resources in a man-made lake in Sri Lanka: a potential supplementary source of income for fishermen. *Fisheries Research*, 9: 81-89.

Amarasinghe, U.S., 1992. Recent trends in the inland fishery of Sri Lanka. In: Baluyut, E.A. (ed.). *FAO Fisheries Report* No. 458, Supplement. Food and Agriculture Organization of the United Nations, Rome.

Amarasinghe, U.S., 1997. Observations on the trends in the cichlid fishery in an ancient reservoir in Sri Lanka. *Journal of the National Aquatic Resources Agency (Sri Lanka)*, 35: 57-68.

Amarasinghe, U.S., 1998a. Reservoir fisheries management in Sri Lanka: Achievements, mistakes and lessons for future. *International Review of Hydrobiology*, 83 (Special Issue): 523-530.

Amarasinghe, U.S., 1998b. How effective are the stocking strategies for the management of reservoir fisheries in Sri Lanka? In: Cowx, I.G. (ed.). *Stocking and Introductions of Fish*. Fishing News Books, Blackwell Science Ltd., Oxford.

Amarasinghe U.S., 2002. The fishery and population dynamics of *Oreochromis mossambicus* and *Oreochromis niloticus* (Osteichthyes, Cichlidae) in a shallow irrigation reservoir in Sri Lanka. *Asian Fisheries Science*, 15(1): 7-20.

Amarasinghe, U.S., 2003. New approaches to inland capture fisheries statistics in Sri Lanka. In: *New approaches for the improvement of inland capture fishery statistics in the Mekong Basin. Ad-hoc expert consultation, 2-5 September 2002, Udon Thani, Thailand*. RAP Publication 2003/01. Food and Agriculture Organization of the United Nations, Bangkok.

Amarasinghe, U.S., 2006. Reservoirs of Sri Lanka: A major source of animal protein for rural communities. In Odada, E.O., Olago, D.O., Ochola, W., Ntiba, M., Wandiga, S., Gichuki, N., Oyieke, H. (eds.). *Proceedings of the 11th World Lake Conference, Nairobi, Kenya, 31 October – 04 November 2005*. International Lake Environment Committee, Japan.

Amarasinghe, U.S., De Silva, S.S., 1992a. Population dynamics of *Oreochromis mossambicus* and *O. niloticus* (Cichlidae) in two reservoirs of Sri Lanka. *Asian Fisheries Science*, 5: 37-61.

Amarasinghe, U.S., De Silva, S.S., 1992b. Empirical approaches for evaluating the efficiencies of different fishing methods in tropical, shallow reservoirs: a Sri Lankan case study. In: De Silva, S.S. (ed.). *Reservoir Fisheries of Asia*. International Development Research Centre, Ottawa, Canada.

Amarasinghe, U.S. De Silva, S. S., 1994. Selectivity patterns in the multi-mesh gillnet fishery for cichlid species in a Sri Lankan reservoir. In: Chou L.M., Munro A.D., Lam T.J., Chen T.W., Cheong L.K.K., Ding J.K., Hooi K.K., Khoo H.W., Phang V.P.E., Shim K.F., & Tan C.H. (eds.). *The Third Asian Fisheries Forum*, Asian Fisheries Society, Manila.

Amarasinghe, U.S. De Silva, S. S., 1999. The Sri Lankan reservoir fishery: a case for introduction of a co-management strategy. *Fisheries Management and Ecology*, 6: 387-399.

Amarasinghe, U.S., Pitcher, T.J., 1986. Assessment of fishing effort in Parakrama Samudra, an ancient man-made lake in Sri Lanka. *Fisheries Research*, 4: 271-282.

Amarasinghe, U.S., Samarakoon, J.I., 1988. Some factors affecting contribution of the cichlid species, *Etroplus suratensis* and *Tilapia rendalli* to the gillnet catches in a man-made lake in Sri Lanka. *Asian Fisheries Science*, 2: 17-26.

Amarasinghe, U.S., De Silva, S.S., Moreau, J., 1989. Spatial changes in growth and mortality and effects on the fishery of *Oreochromis mossambicus* (Pisces, Cichlidae) in a man-made lake in Sri Lanka. *Asian Fisheries Science*, 3: 57-68.

Amarasinghe, U.S., Ajith Kumara, P.A.D., Ariyaratne, M.H.S., 2002a. Role of non-exploited fishery resources in Sri Lankan reservoirs as a source of food for cage aquaculture. In: Cowx, I.G. (ed.). *Management and Ecology of Lake and Reservoir Fisheries*. Fishing News Books, Blackwell Science Ltd., Oxford, U.K.

Amarasinghe, U.S., De Silva, S.S., Nissanka, C., 2002b. Evaluation of the robustness of predictive yield models based on catchment characteristics using GIS for reservoir fisheries in Sri Lanka. *Fisheries Management and Ecology*, 9: 293-302.

Amarasinghe, U.S., Shirantha, R.R.A.R., Wijeyaratne, M.J.S., 2006. Some aspects of ecology of endemic freshwater fishes of Sri Lanka. In: C.N.B. Bambaradeniya (ed.), *The Fauna of Sri Lanka: Status, Taxonomy, Research and Conservation*. The World Conservation Union (IUCN), Colombo, Sri Lanka and Government of Sri Lanka.

Balasuriya, L.K.S.W., Tilak, C.R., Kumarasiri, W.S.A.A.L., Sirisena, H.K.G., 1983. Induced breeding of Indian carps in Sri Lanka. *Journal of Inland Fisheries*, 2: 63-67.

Berkes, F., 1994. Co-management: Bridging the two solitudes. *Northern Perspectives*, 22: 18-20.

Chakrabarty, R.D., Samaranayake, R.A.D.B., 1983. Fish culture in seasonal tanks in Sri Lanka. *Journal of Inland Fisheries*, 2: 125-140.

Chandrasoma, J., 1986. Trends in reservoir fisheries in Sri Lanka with special reference to *Etroplus suratensis*, *Tilapia rendalli* and *Oreochromis niloticus*. In: Maclean, J.L., Dizon, L.B., and Hosillos, L.V. (eds.) *The first Asian fisheries forum*. Asian Fisheries Society, Manila, Philippines.

Chandrasoma, J., 1992. Performance of rohu, *Labeo rohita* (Ham.), in some perennial and seasonal reservoirs of Sri Lanka – an evaluation. *Journal of Applied Ichthyology*, 8: 228-233.

Chandrasoma, J., Kumarasiri, W.S.A.A.L., 1986. Observations on polyculture of fish in seasonal tanks in Ratnapura and Moneragala districts in Sri Lanka. *Journal of Inland Fisheries*, 3: 49-55.

Costa, H.H., Abayasiri, R., 1978. The limnology of Colombo (Beira) lake 7. Food and feeding ecology of the fish, *Tilapia mossambica*. *Spolia Zeylanica*, 32: 94-110.

Costa, H.H., de Silva, P.K., 1995. Limnological research and training in Sri Lanka: State of the art and future needs. In: B. Gopal and R.G. Wetzel (eds.) *Limnology in Developing Countries, Volume 1.* International Association for Limnology Publication, International Scientific Publication, New Delhi, India.

Cowx, I.G., 1994. Stocking strategies. *Fisheries Management and Ecology,* 1: 15-30.

De Silva, S.S., 1985. Body condition and nutritional ecology of *Oreochromis mossambicus* (Pisces, Cichlidae) populations in man-made lakes in Sri Lanka. *Journal of Fish Biology*, 27: 621-633.

De Silva, S.S., 1987. Stocking practices in Sri Lanka. In: Petr, T. (ed.) Reports and papers presented at the Indo-Pacific Fisheries Commission Expert Consultation on the Inland Fisheries of Larger Indo-Pacific Countries. *FAO Fisheries Report*, 371 (Supplement): 223-232. Food and Agriculture Organization of the United Nations, Rome.

De Silva, S.S., 1988. Reservoirs of Sri Lanka and their fisheries. *FAO Fisheries Technical Paper*, 298. Food and Agriculture Organization of the United Nations, Rome.

De Silva, S.S., 2003. Culture-based fisheries: An underutilized opportunity in aquaculture development. *Aquaculture*, 221: 221-243.

De Silva, S.S., Sirisena, H.K.G., 1987. New fish resources of reservoirs in Sri Lanka: Feasibility of introduction of a subsidiary gillnet fishery for minor cyprinids. *Fisheries Research*, 6: 17-34.

De Silva, S.S., Sirisena, H.K.G., 1989. New fish resources of reservoirs in Sri Lanka. 3. Results of commercial-scale trials and yield estimates of a gillnet fishery for minor cyprinids. *Fisheries Research*, 7: 279-287.

De Silva, S.S., Lin, Y., Tan, G., 1992. Possible yield-predictive models based on morphometric characteristics and stocking rates for three groups of Chinese reservoirs. *Fisheries Research*, 13: 369-390.

De Silva, S.S., Wijenayake, W.M.H.K., Gunaratne, A.B.A.K., Amarasinghe, U.S., 2005. Use of GIS tools to develop a scale for the selection of non-perennial reservoirs for culture-based fisheries activities. In: Nishida, T., Kailola, P.J. and Hollingworth, C.E. (eds.). *GIS Spatial Analyses in Fishery and Aquatic Sciences* (Volume 2). Fishery and Aquatic GIS Research Group, Japan.

FAO/UNDP, 1980. *Strategy for development of aquaculture in Sri Lanka. Report of a planning mission, September-October 1980*. ADCP/MR/81/15.

Fernando, C.H., 1967. The beach seine fishery in Ceylon's freshwaters. *Indo-Pacific Fisheries Council Current Affairs Bulletin,* No. 50.

Fernando, C.H.,1984. Reservoirs and lakes of Southeast Asia (Oriental region). In: Taub, F.B. (ed.). *Lake and Reservoir Ecosystems.* Elsevier, Amsterdam, The Netherlands.

Fernando, C.H., 1993, Impact of Sri Lankan reservoirs, their fisheries, management and conservation. In: Erdelen,W., Preu, C., Ishwaran, N. and Bandara, C.M.M. (eds.). *Ecology and Landscape Management in Sri Lanka, Proceedings of the International and Interdisciplinary Symposium 12-16 March 1990, Colombo, Sri Lanka.* Margraf Scientific Books, Weikersheim.

Fernando, C.H., 2000. A view of the inland fisheries of Sri Lanka: Past, present and future. *Sri Lanka Journal of Aquatic Science*, 5: 1-26.

Fernando, C.H., Ellepola, W.B., 1969. A preliminary study of two village tanks (reservoirs) in the Polonnaruwa area with biological notes on these reservoirs in Ceylon. *Bulletin of Fisheries Research Station, Ceylon,* 20: 3-13.

Fernando, C.H., Holcik, J., 1991. Fish in reservoirs. *Internationale Revue gesamten Hydrobiologie,* 76: 149-167.

Fernando, C.H. and H.H.A. Indrasena, 1969. The freshwater fisheries of Ceylon. *Bulletin of Fisheries Research Station, Ceylon* 20: 101-134.

Fernando, C.H., Weerawardhena, S.R., 2002. *Sri Lanka freshwater fauna and fisheries.* Volume Publishing, Kitchener, Ontario, Canada.

Garcia, S.M., Zerbi, A., Aliaume, C., Do Chi, T., Lasserre. G., 2003. The ecosystem approach to fisheries: Issues, terminology, principles, institutional foundation, implementation and outlook. *FAO Fisheries Technical Paper* No. 443. Food and Agriculture Organization of the United Nations, Rome.

Gayanilo Jr. F.C., Sparre, P., Pauly, D., 1996. The FAO-ICLARM Stock Assessment Tools (FiSAT) User's Guide. *FAO Computerized Information Series (Fisheries)*, No. 8. Food and Agriculture Organization of the United Nations, Rome.

Indrasena, H.H.A., 1965. The development of fresh water fisheries in Ceylon. Proceedings of the Symposium on the Development of Ceylon's Fisheries. *Bulletin of Fisheries Research Station, Ceylon,* 17: 287-289.

Li, S., 1988. The principles and strategies of fish culture in Chinese reservoirs. In: S.S. De Silva (ed.). *Reservoir Fishery Management and Development in Asia.* International Development Research Centre, Ottawa.

Lorenzen, K., 2001. Using population models to assess culture-based fisheries: A brief review with an application to the analysis of stocking experiments. In: De Silva, S.S. (ed.). *Reservoir and Culture-based Fisheries: Biology and Management*. ACIAR Proceedings No. 98, Australian Centre for International Agricultural Research, Canberra.

Mendis, A.S., 1965. A preliminary survey of 21 Ceylon lakes. 2. Limnology and fish production potential. *Bulletin of Fisheries Research Station, Ceylon,* 16: 7-16.

Mendis, A.S., 1977. The role of man-made lakes in the development of fisheries in Sri Lanka. *Proceedings of Indo-Pacific Fisheries Council,* 17(3): 247-254.

Meaden, G.J., Kapetsky, J.M., 1991. Geographical information systems and remote sensing in inland fisheries and aquaculture. *FAO Fisheries Technical Paper,* 318. Food and Agriculture Organization of the United Nations, Rome.

Middendrop, H.A.J., Balarin, J.D., 1999. Fisheries enhancement and participatory resource management: two types of management in the oxbow lakes projects in Bangladesh. In: Middendrop, H.A.J., Thompson, P.M. and Pomeroy, R.S. (eds.). *Sustainable Inland Fisheries Management in Bangladesh. ICLARM Conference Proceedings Vol. 58, ICLARM, Manila.*

Moreau, J., Villanueva, M.C., Amarasinghe, U.S., Schiemer, F., 2001. Trophic relationships and possible evolution of the production under various fisheries management strategies in a Sri Lankan reservoir. In: De Silva, S.S. (ed.) *Reservoir and Culture-based Fisheries: Biology and Management.* ACIAR, Canberra, Australia.

Nathanael, S., Edirisinghe, U., 2002. Developing co-management in an artisanal gill net fishery of a deep hydro-electric reservoir in Sri Lanka. *Fisheries Management and Ecology,* 9: 267–276.

Naylor, R.L., Goldburg, R.J., Primavera, J., Kautsky, N., Beveridge, M.C.M., Clay, J., Folkes, J., Lubchence, M.H., Troell, M., 2000. Effects of aquaculture on world food supplies. *Nature* 405: 1017-1024.

Newrkla, P., Duncan, A., 1984. The biology and density of *Ehirava fluviatilis* (clupeiod) in Parakrama Samudra, Sri Lanka. *Verhandlungen der internationale Vereinigung für theoretische und angewandte Limnologie*, 22: 1572-1578.

Neis, B., Schneider, D.C., Felt, L., Haedrich, R.L., Fischer, J., Hutchings, J.A., 1999. Fisheries assessment: What can be learned from interviewing resource users? *Canadian Journal of Fisheries and Aquatic Sciences,* 56: 1949-1963.

Nguyen H.S., Bui, A.T., Le, L.T., Nguyen, T.T.T., De Silva, S.S., 2001. The culture-based fisheries in small, farmer-managed reservoirs in two provinces of northern Vietnam: an evaluation based on three production cycles. *Aquaculture Research,* 32: 975–990.

Nissanka, C., 2001. *Empirical models for fish yield prediction in selected reservoirs in the dry zone of Sri Lanka.* Unpublished Ph.D. Thesis, University of Kelaniya, Sri Lanka.

Oglesby, R.T., 1981. *A synthesis of the reservoir fisheries in Sri Lanka*. FI: TCP/SRL/8804 Field Document 2. Food and Agriculture Organization of the United Nations, Rome.

Panabokke, C.R., 2001. The nature and properties of small tank systems of the dry zone and their sustainable production thresholds. In: Gunasena, H.P.M. (ed.). *Food security and small tank systems in Sri Lanka. Proceedings of the workshop organized by the working committee on agricultural science and forestry, 9 September 2000*. National Science Foundation, Colombo.

Pauly, D., Morgan, G.R. (eds.), 1987. Length-based methods in fisheries research. *ICLARM Conference Proceedings* No. 13. International Centre for Living Aquatic Resources Management, Manila, Philippines and Kuwait Institute for Scientific Research, Safat, Kuwait.

Pet, J.S., Piet, G.J., 1993. The consequences of habitat occupation and habitat overlap of the introduced *Oreochromis mossambicus* and indigenous fish species for fishery management in a Sri Lankan reservoir. *Journal of Fish Biology*, 43 (Supplement): 193-208.

Pet, J.S., Gevers, G.J.M., van Densen, W.L.T., Vijverberg, J., 1996. Management options for a more complete utilization of the biological fish production in Sri Lankan reservoirs. *Ecology of Freshwater Fish*, 5: 1-14.

Pethiyagoda, R., 2006. Conservation of Sri Lankan freshwater fishes. In: Bambaradeniya, C.N.B. (ed.). *The Fauna of Sri Lanka: Status, Taxonomy, Research and Conservation*. The World Conservation Union (IUCN), Colombo, Sri Lanka and Government of Sri Lanka.

Piet, G.J., Vijverberg, J., 1998. An ecosystem perspective for the management of a tropical reservoir fishery. *International Review of Hydrobiology*, 83 (Special Issue): 103-112.

Pomeroy, R.S., 1995. Community-based and co-management institutions for sustainable coastal fisheries management in Southeast Asia. *Ocean and Coastal Management*, 27: 143-162.

Pushpalatha, K.B.C., 2001. Community-based freshwater fish culture in Sri Lanka. In: De Silva, S.S. (ed.), *Reservoir and Culture-based Fisheries: Biology and Management*. ACIAR Proceedings No. 98, Australian Centre for International Agricultural Research, Canberra.

Pushpalatha, K.B.C., Amarasinghe, U.S., 2007. *Co-management strategies for the development of culture-based fisheries in village reservoirs of Sri Lanka*. Paper presented at the Eighth Asian Fisheries Forum, 21-23 November 2007, Kochi, India.

Rosenthal, H., 1979. *Preliminary report and recommendations on reservoir and tank stocking activities in inland fisheries in Sri Lanka*. Interim Report to FAO for the Project TCP/SRL/8804, Development of fisheries in the man-made lakes and reservoirs. Food and Agriculture Organization of the United Nations, Rome.

Saaty, T.L., 1977. A scaling method for priorities in hierarchical structures. *Journal of Mathematical Psychology*, 15: 234-281.

Schiemer, F., Hofer, R., 1983. A contribution to the ecology of the fish fauna of the Parakrama Samudra reservoir. In: Schiemer, F. (ed.). *Limnology of Parakrama Samudra - Sri Lanka*. Dr. W. Junk Publishers, The Hague, The Netherlands.

Sen, S. and Raajaer-Nielsen, J., 1996. Fisheries co-management: a comparative analysis. *Marine Policy*, 20: 405-418.

Shirantha, R.R.A.R., Amarasinghe, U.S., 2006. Alien ichthyofauna and aquatic biodiversity in torrential rivering habitats of Sri Lanka. *Proceedings of the International Conference on Humid Tropical Ecosystems: Changes, Challenges and Opportunities, Kandy, Sri Lanka, 4-9 December 2006*.

Silva, E. I. L., Davies, R. W., 1988. Notes on the biology of *Hemiramphus limbatus* (Hemiramphidae: Pisces) in Sri Lanka. *Tropical Freshwater Biology*, 1: 42–49.

Siriweera, W.I., 1986. The inland fishery in Sri Lanka: A historical perspective. *Occasional Publication* No. 33. Agrarian Services and Training Institute, Colombo, Sri Lanka.

Siriweera, W.I., 1994. *A study of the economic history of pre-modern Sri Lanka*. Vikas Publishing House Pvt Ltd., Jangpura, New Dheli, India.

Sricharoendham, B., Amarasinghe, U.S., Jayasinghe, R.P.P., Kaypa, S.M., 2008. Status of the capture fisheries in four Asian reservoirs and a volcanic lake. In: Schiemer, F., Simon, D., Amarasinghe, U.S. and Moreau, J. (eds.). *Aquatic Ecosystem and Development: Comparative Asian Perspectives*. Biology of Inland Waters Series, Backhuys Publishers, Leiden, The Netherlands.

Sugunan, V.V., 1995. Reservoir fisheries of India. *FAO Fisheries Technical Paper*, 345. Food and Agriculture Organization of the United Nations, Rome.

Thayaparan, K., 1982. The role of seasonal tanks in the development of freshwater fisheries in Sri Lanka. *Journal of Inland Fisheries*, 1: 133-167.

Ticheler, H.J., Kolding, J., Chanda, B., 1998. Participation of local fishermen in scientific fisheries data collection: a case study from Bangweulu swamps, Zambia. *Fisheries Management and Ecology*, 5: 81-92.

Ulluwishewa, R., 1995. Traditional practices of inland fishery resources management in the dry zone of Sri Lanka: implications for sustainability. *Environmental Conservation*, 22: 127-132.

Villanueva M.C., J. Moreau, U.S. Amarasinghe, Schiemer, F., in press. A comparison of the foodweb and the trophic structure between two Asian reservoirs by using ECOPATH with ECOSIM and ECOSPACE. In: Schiemer, F., Simon, D., Amarasinghe, U.S. and Moreau, J. (eds.). *Aquatic Ecosystem and Development: Comparative Asian Perspectives*. Biology of Inland Waters Series, Backhuys Publishers, Leiden, The Netherlands.

Welcomme, R.L., Bartley, D.M., 1998. Current approaches to the enhancement of fisheries. *Fisheries management and Ecology*, 5: 351-382.

Weliange, W.S., Amarasinghe, U.S., Kakkaeo, M., Sricharoendham, B., Schiemer F., Lopez, N.C., 2008. Trophic patterns of fish assemblages in five Asian lacustrine water bodies. In: Schiemer, F., Simon, D., Amarasinghe, U.S. and Moreau, J. (eds.). *Aquatic Ecosystem and Development: Comparative Asian Perspectives*. Biology of Inland Waters Series, Backhuys Publishers, Leiden, The Netherlands.

Weerakoon, D.E.M., 1979. Induced breeding of two major species of Chinese carps, *Ctenopharyngodon idellus* and *Aristichthys nobilis* in Sri Lanka. *Bulletin of Fisheries Research Station, Sri Lanka*, 29: 55-62.

Wijenayake, W.M.H.K., Jayasinghe, U.A.D., Amarasinghe, U.S., Gunaratne, A.B.A.K., De Silva, S.S., 2005. Quantification of morphometric characteristics and aquatic vegetation cover in non-perennial reservoirs using remote sensing techniques for planning culture-based fisheries. *Proceedings of the International Workshop on Fisheries and Aquatic Research in Sri Lanka*. 29-31 March 2005, NARA, Colombo, Sri Lanka.

Wijeyaratne, M.J.S., Amarasinghe, U.S., 1987. Estimations of maximum sustainable fish yield and stocking densities of fish fingerlings in freshwater lakes and reservoirs. *Archiv für Hydrobiologie, Beiheft Ergebnisse der Limnologie*, 28: 305-308.

Reservoir Fisheries of Thailand

Tuantong Jutagate

Fisheries Programme, Faculty of Agriculture, Ubon Ratchathani University
Warin Chamrab, Ubon Ratchathani, Thailand 34190.

Introduction

Thailand has a coastline of 2,614 km and 3,750 km^2 of inland water area (TDRI, 1987). Inland fisheries have been long recognised and operated in the major rivers, floodplains, canals, swamps, wetlands, lakes and reservoirs. According to zoogeographical classification, there are seven major river basins in the country *viz*. Chao Phraya Basin, Mekong Basin, Eastern Basin, Southern Basin, Salween Basin, Mekhlong Basin and Tenasserim Basin (Satapornwanit and Wongrat, 2000). Natural lakes in Thailand include Bung Borapet in the Central Region (13,000 ha), Nong Harn in the Northeastern Region (12,500 ha), Kwan Phyao in the Northern Region (2,100 ha) and Songkla Lake (96,000 ha) in the south (Pawaputanon, 1992). Most of the Thai reservoirs were impounded in the second half of 20th century (De Silva and Funge-Smith, 2005). The freshwater fish fauna in Thailand is very diverse with approximately 573 indigenous species and 16 introduced species (Vidthayanon *et al*., 1997).

Fisheries resources in Thailand are regarded as a public wealth (Bhukaswan, 1987) and fishing is a long standing tradition in the country, considered an integral part of the heritage and culture, particularly in rural areas of Thailand (Coates, 2002). Fish yield from inland fisheries contributes about 7.3 % to the country’s overall fish landings and provides about 3 kg caput^{-1} yr^{-1} (De Silva and Funge-Smith, 2005).

Inland fisheries production has increased over the years from about 200,000 t in 1995 (Virapat and Mattson, 2001) to about 203,000 t in 2004 (Department of Fisheries, 2007). The proportion of the total production from various habitats is as follows: rivers, streams and canals (34.2%); swamps/marsh/floodplain (31.3 %); rice-fields (22.2 %); reservoirs (8.3 %); lakes (2.1 %); and aquaculture ponds (2.0%) (Coates, 2002). The inland fisheries are essentially artisanal and are based mainly on the indigenous species (80-90 %) such as carps, minnows, snakeheads and catfishes (Virapat and Mattson, 2001). The rest constitute the introduced species such as tilapias as well as Indian and Chinese major carps. When the country is divided into four regions (i.e. North, Northeast, South and Central), the highest production in inland capture fisheries is reported from the northeastern region (40.8 %) and the lowest production (10.4 %) is in the south (Satapornwanit and Wongrat, 2000).

Reservoir fisheries in Thailand

Reservoirs in Thailand are ubiquitous countrywide (Figure 1), especially in the North and Northeastern regions. They have been impounded for either hydropower or irrigation purposes, and fisheries are considered a secondary benefit from the impoundments. However, there are to Thai reservoirs, which were impounded and used primarily for fisheries (Virapat and Mattson, 2001). Virapat *et al.* (2000) gave an estimated inventory of 28,956 reservoirs in Thailand ranging from 0.01 ha to more than 1000 ha. According to Virapat and Mattson (2001) however, there are 27,779 Thai reservoirs. Virapat *et al.* (2000) also estimated fish production from these reservoirs to be between 122,314 and 318,909 t per year.

Figure 1. Distribution of the major reservoirs in Thailand (Bernacsek, 1997).

General aspects

Most of the Thai reservoirs have relatively small catchment areas (<10,000 km^2). The water storage volume ranges from 108.5 million cubic metres in Mae Chang to 17,745 million cubic metres in Srinagarind (Bernacsek, 1997). The surface area of major reservoirs in Thailand ranges from 1,200 to 41,000 ha (Table 1, Verdegem, 1999) and the cumulative area of Thai reservoirs is 432,176 ha (Virapat and Mattson, 2001) which is significantly higher compared to the approximation of about 3 x 10^5 ha (De Silva and Amarasinghe, 1996; Bernacsek 1997).

In Ubolratana reservoir, one of the largest reservoirs in the country, the pelagic fish catch is found to be significantly related to the surface area variation while the littoral catch is related to the total reservoir area and to the difference between the minimum and maximum water spread of reservoir (Moreau *et al.*, 2004). Sihapitukgiat *et al.* (2002) also reported that the monthly catch in Ubolratana Reservior showed a positive significant relationships to the monthly rainfall ($r = 0.4638$, $p<0.01$) and monthly inflow ($r = 0.3241$, $p<0.01$) but was inversely correlated to the reservoir water level ($r= -0.3286$, $p<0.01$) and water storage volume ($r = -0.3024$, $p<0.05$).

Table 1. Main features of some of the major reservoirs in Thailand.

Reservoir	Surface area (ha)	Mean depth (m)	Catchment area (km^2)	Man annual yield (t)	Year of impoundment
Ubolratana	41,000	15.8	12,160	2,274.0	1965
Srinakarinth	40,000	44.6	10,880	371.0	1977
Khoa Lam	35,320	24.0	3,720	520.0	1984
Bhumiphol	30,000	44.7	25,390	852.9	1964
Sirinthorn	29,200	5.1	2,100	1,277.2	1971
Sirikit	28,400	36.8	13,130	1,047.6	1972
Lam Poa	23,000	5.5	5,950	1,514.9	1968
Chiew Larn	16,700	25.2	NA	NA	1986
Nam Oon	8,600	6.4	1,100	211.4	1973
Kang Krachan	4,970	14.3	2,210	322.2	1966
Krasiew	4,800	5.0	1,220	425.0	1980
Pranburi	4,670	11.0	3,030	190.2	1976
Bang Lang	4,500	30.2	2,080	54.9	1980
Lam Takong	4,430	10.0	1,340	100.0	1968
Nam Pong	2,100	8.6	300	131.0	1966
Lam Praplerng	1,860	11.0	NA	NA	1969
Rachaprabha	1,840	34	1,450	478.0	1987
Kew Lom	1,800	6.7	2,700	148.0	1972
Bang Phra	1,760	7.0	130	48.5	1975
Chulabhorn	1,200	15.7	50	38.0	1972
Pasak Jolasid	18,259	16	NA	NA	1998
Pak Mun	17,000	8	NA	NA	1994

Chemical properties varied from reservoir to reservoir (Table 2). The morphoedaphic index (MEI; the ratio of conductivity to the mean depth) showed a very highly skewed distribution with no relationship to fish yield (Bernacsek, 1997).

Table 2. Important water qualities of some of the major reservoirs of Thailand.

Reservoir	Alkalinity (mg/l)	Hardness (mg/l)	Conductivity (µcm)	DO (mg/l)	CO_2 (mg/l)
Ubolratana	71	65	150	3.4-10.2	NA
Srinakarinth	129	120	265	6.0-8.4	0.5-2
Khoa Lam	75	60	136	4.4-7.4	0.1-10
Bhumiphol	75	68	172	7.2-8.5	0.1-12
Sirinthorn	15	91.5	25	5.3-6.8	8.1-15
Sirikit	86	78	168	6.0-8.0	2.0-15
Lam Poa	102	48	NA	5.0-9.0	2.0-6.0
Kang Krachan	68	70	115	6.4-12	0-4.2
Krasiew	140	126	NA	4.4-8.0	0-3
Pranburi	90	100	NA	NA	NA
Bang Lang	40	45	215	4.9-7.6	2?
Lam Takong	221	164	300	6.3-7.5	0.8-7.8
Nam Pong	30	26	50	5.4-8.3	2.9-31.7
Rachaprabha	32	39	73	4.3-6.9	2.5-10.5
Kew Lom	140	140	NA	4.4-7.9	0.5-1.5
Chulabhorn	60	48	105	4.0-7.5	0.5-1.4
Pak Mun	60	51	NA	3.8-14.3	1.4-10.9

Fish communities

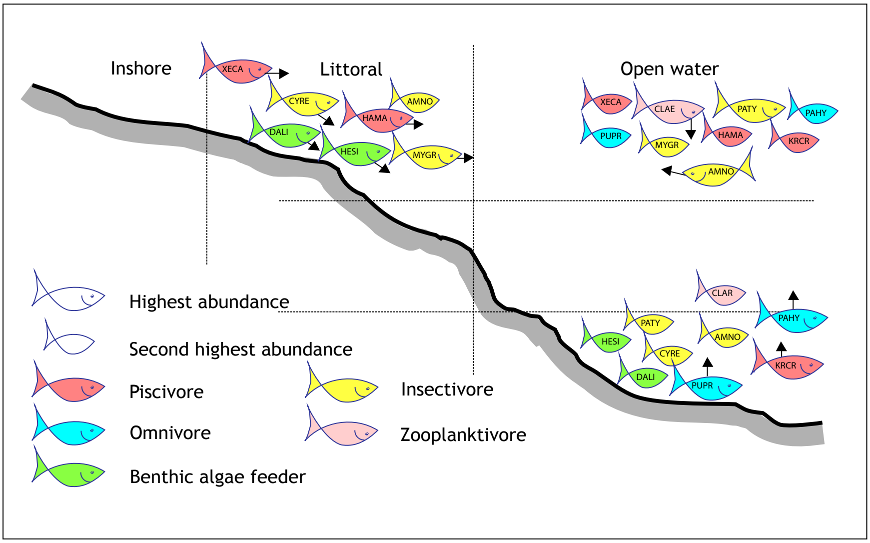
In all Thai reservoirs, structure of fish assemblages is of more or less similar magnitude. The reservoir fish communities consist of cyprinids, which form over 50 %, followed by catfishes, murrels, and miscellaneous species. The exotic species are the Chinese and Indian carps as well as Nile tilapia. There is also evidence that changes of fish species composition occurred after impoundment, For example, in Sirindhorn Reservoir a decline of large true piscivores such as snakehead and *Hampala* spp. and increase of the abundance of *Notopterus* spp., compressed perch *Pristolepis fasciatus*, *Puntius* spp. and *Dangila* spp. were reported in (Srichareondham *et al*., 2000).

In reservoir fish communities, there appear to be marked differences in distribution of species in the inshore and offshore areas. The small sized species such as Thai river sprat *Clupeichthys aesarnensis*, silver knife barb *Paraluebuca typus*, pointed nose sensory barb *Cyclocheilichthys repasson* and glass fish *Ambassis notatus* are caught in the offshore area where as the medium to large sized species such as spotted wolf barb *Hampala dispar*, carp *Dangila lineartus*, common Siamese barb *Henicorhynchus siamensis*, red spotted robust labeo *Osteochilus hasselti*, Lin robust labeo *Osteochilus lini*, three spot gourami

Trichogaster trichopterus and green tail snakehead *Channa striata* are found in higher abundance in inshore area (Figure 2, Sihapitukgiat *et al.*, 2002).

Prchalová *et al.* (2003), based on hydroacoustic studies, investigated the vertical distribution of fish in Ubolratana reservoir. During daytime, most fish species followed a general tendency of forming shoals or staying near the bottom and during early dusk, shoals disintegrated and single fish appeared mostly in deeper layers. At night, the entire water column was filled with organisms as most fish moved gradually to the upper part of the water column (0–5 m) and stayed there throughout the night.

Figure 2. Distribution of dominant fish in Ubolratana Reservoir.



Note: Cyclocheilichthys repasson (CYRE), Mystacoleucus greenwayi (MYGR), Hampala macrolepidota (HAMA), Dangila lineatus (DALI), Henicorhynchus siamensis (HESI), Xenentodon cancila (XECA), Ambassis notatus (AMNO), Clupeichthys aesarnensis (CLAE), Paralaubuca typus (PATY), Puntioplites proctozysron (PUPR), Kryptopterus cryptopterus (KRCR) and Pangasianodon hypophthalamus.

Trophic status

In Thai reservoirs, the ratio of predator-prey biomass is above 0.3 and in Ubolratana it is as high as 0.5 implying the high abundance of predators (Chookajorn *et al.*, 1994; Jutagate *et al.*, 2002; Thappanand *et al.*, 2008). However, the ecosystems balance still exists due to the high production per biomass (P/B ratio or turnover rate, which is approximately equals total mortality coefficient) of the prey compared to those of the predators (Jutagate *et al.*, 2002). Schiemer *et al.* (2001) also stated that herbivores in Thai reservoirs appear to be of a distinctly lower significance.

The gross efficiency of the fisheries production (i.e. actual catch/ primary production) in Ubolratana reservoir was about 0.003 (Chookajorn *et al*., 1994) and was about 0.005 in Sirindhorn (Jutagate *et al*., 2002). These figures imply the underutilised food resources in the system at Ubolratana Reservoir and fully utilised food resources resulting high biological productivity in Sirindhorn Reservoir. The fish biomass in Ubolratana reservoir was less than 10 t km^{-2} but was over 25 t km^{-2} as in Sirindhorn Reservoir (Thappanand *et al*., 2008). Sidthimunka *et al*. (1978) reported that the biomass of benthic animals including annelids, crustaceans, mollusks and insects in Thai reservoirs, can fluctuate between 6 and 16 t km^{-2}.

Fisheries

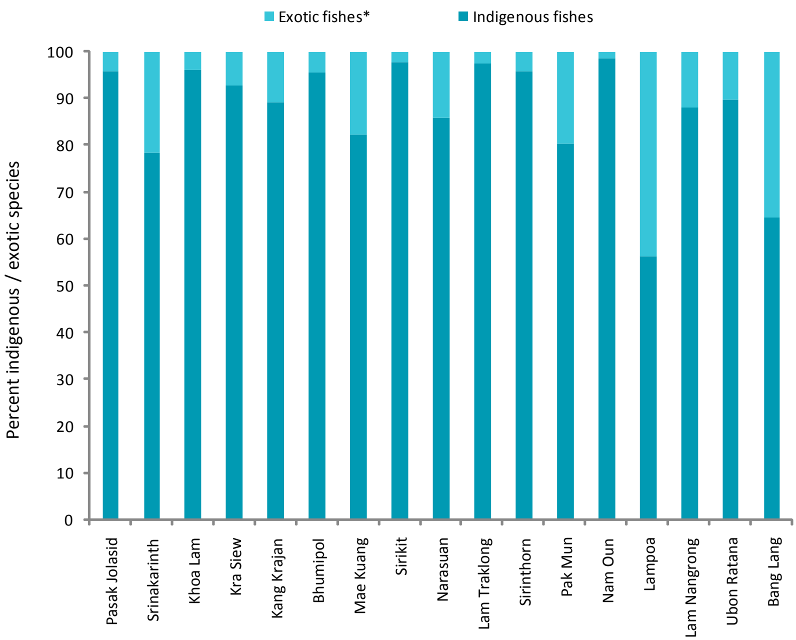
The majority of fishers in the Thai reservoirs are subsistence fishers. They use different gears based on season, water level and fishing ground. The fish landings are mostly of indigenous species, which form over 80 percent of the production (Figure 3 and Box 1). In general, most fishers use gillnets, longlines, cast nets, scoop nets and big lift nets. Gill net mesh sizes range from 2.5 to 18 cm, and 4.5 to 7.0 cm are the most popular. The larger mesh gillnets are used during the rainy season. For the longlines, the hook sizes range from 2.7 (hook No. 23) to 22.7 mm (Hook No. 4) (Jutagate and Mattson, 2003). There are two types of lift nets; fixed lift-nets and movable lift-nets. These are used for catching small clupeids. The net dimension of lift net is of 8x8 m^2 and mesh size is 2.5 cm (Sihapitukgiat *et al*., 2002).

Except for the lift net fisheries for the small clupeid *C. aesarnensis* in Northeastern region reservoirs (Sirimongkolthaworn 1992; Jutagate *et al*., 2003a), the fishing is often not targeted. The reservoir fishers take all species regardless of size variation (Bhukaswan and Chookajorn, 1988). The average fish yield in Thai reservoirs is about 48 kg $ha^{-1}yr^{-1}$ (Bhukaswan and Chookajorn, 1988; Moreau and De Silva, 1991). The empirical model between catch per unit effort and fishing effort in Thai reservoirs showed that the estimated maximum sustained yield and optimum fishing effort were 93 kg ha^{-1} yr^{-1} and 10 fishers km^{-2}, respectively (De Silva *et al*., 1991).

Stock enhancement programmes

Stock enhancement in Thai reservoirs has been carried out since the early 1950s (Pawaputanon, 1992). During 1960s to 1980s, introduction of Chinese and Indian carps was widely practiced in the inland water bodies countrywide. In Thailand, stocking programs are not only carried out in reservoirs but also in rice-fields, rivers and swamps. Stocking is generally considered as a means of providing benefits to poor communities (Coates, 2002). The popular species stocked are grass carp *Ctenopharyngodon idella*, mud carp *Cirrhinus molitorella*, silver carp *Hypophthalmichthys molitrix*, common carp *Cyprinus carpio*, bighead carp *Aristichthys nobilis* (Pholprasit and Waiwuttho, 1970; Benchakarn, 1972; Duangswasdi and Janesirisak, 1973), mrigal *Cirrhinus mrigala* and rohu *Labeo* *rohita* (Benchakarn and Nookuor, 1988; Pawaputanon, 1988). Amongst exotics, Indian carps are thought to perform better than Chinese carps because Indian carps showed the better survival and yields (Virapat, 1993).

Figure 3. Percentage contribution of exotic and indigenous species in the catches of some major Thai reservoirs. Note: Exotic fishes includes giant freshwater prawn.



Since the early 1990s, stocking programs have been shifted from exotics to indigenous species (Table 3). The popular species to be stocked are silver barb *Barbonymus gonionotus*, seven-line barb *Probarbus jullieni*, broad-head walking catfish *Clarias macrocephalus*, common Siamese barb *Henicorhynchus siamensis*, iridescent shark catfish *Pangasianodon hypophthalmus*, tinfoil barb *Barbodes schwanenfeldi*, golden barb *Barbonymus altus*, black eye shark catfish *Pangasius larnaudii* and tiny scale barb *Thynnichthys thynnoides*. The Mekong giant catfish *Pangasianodon gigas*, which is listed as a critically endangered species (Hogan, 2004), is also popular for stocking. Its performance in the reservoir environment was investigated with regard to various aspects such as feeding habits, which comprised both phytoplankton and zooplankton (Yamagichi *et al.*, 2005a, 2005b), and its preferred habitat during both day and night, where it stayed shallower at night, deeper during the day and avoided hypoxia areas of the reservoir (Mitaura *et al.*, 2005) and reproductive biology in the reservoir habitats (Manosroi *et al.*, 2003). Fish stocking is carried out with the objectives of improving the fish yield in reservoirs and conserving economically important indigenous species, through a project under the patronage of Her Majesty the

Box 1. Fish species caught in the fisheries of Thai reservoirs.

Family Notopteridae (featherbacks)	
Notopterus notopterus (Pallas)	Bronze featherback
Chitala spp.	Featherback
Family Clupeidae (herrings)	
Clupeichthys aesarnensis (Wongratana)	Thai river sprat
Family Cyprinidae (carps or barbs)	
Cyprinus capio (L.)	Common carp
Hypophthalmichthys molitrix (Val.)	Bighead carp
Paralaubuca typus (Bleeker)	Silver knife barb
Rasbora spp.	Rasbora
Leptobarbus hoeveni (Bleeker)	Mad barb
Probarbus jullieni (Sauvage)	Seven-line barb
Thynnichthys thynnoides (Bleeker)	Tiny scale barb
Cyclocheilichthys repasson (Bleeker)	Pointed nose sensory barb
Puntioplites proctozysron (Bleeker)	Cubic barb
Puntioplites falcifer (Smith)	Longfin cubic barb
Barbodes gonionotus (Bleeker)	Java barb
Barbodes schwanenfeldi (Bleeker)	Tinfoil barb
Hampala spp.	Wolf barb
Puntius orphoides (Val.)	Red cheek common barb
Henicorhynchus siamensis (Sauvage)	Common Siamese barb
Cirrhinus mrigala (Hamilton)	Mrigal
Morulius chrysophekadion (Bleeker)	Crow Labeo
Labeo rohita (Hamilton)	Rohu
Osteochilus spp.	Robust labeo
Family Bagridae (Bagrid catfishes)	
Mystus singaringan (Bleeker)	Long adipose mystus
Family Pangasiidae (river catfishes)	
Pangasianodon gigas (Chevey)	Mekong giant catfish
Pangasianodon hypophthalmus (Sauvage)	Iridescent shark catfish
Pangasius larnaudii (Boucourt)	Black eye shark catfish
Family Siluridae (sheathfish)	
Kryptopterus spp.	Chevey sheathfish
Ompok siluroides (Lecepede)	Black ear sheathfish
Wallago attu (Schneider)	Crocodile sheathfish
Family Clariidae (walking catfishes)	
Clarias spp.	Walking catfish
Family Synbranchidae (swamp eels)	
Monopterus albus (Zieuw)	Swamp eel
Family Mastacembelidae (spiny eels)	
Macrognathus semiocellatus (Roberts)	Ocellated spiny eel
Macroghathus siamensis (Gunther)	Peacock spiny eel
Family Ambassidae (glassfishes)	
Parambassis siamensis (Fowler)	Siamese glassfish
Family Cichlidae (cichlids)	
Oreochromis niloticus (L.)	Nile tilapia

Family Eleotridae (sleepers)	
Oxyeleotris marmorata (Bleeker)	Marbled sleeper goby
Family Nandidae (leaffishes)	
Pristolepis fasciatus (Bleeker)	Compressed perch
Family Anabantidae (climbing perch)	
Anabas testudineus (Bloch)	Climbing perch
Family Belontiidae (gouramies)	
Trichogaster pectoralis (Regan)	Snakeskin gourami
Trichogaster trichopterus (Pallas)	Three spot gourami
Family Osphronemidae (giant gouramies)	
Osphronemus goramy (Lacepede)	Giant gourami
Family Channidae (snakeheads)	
Channa lucius (Cuv.)	Marble snakehead
Channa striata (Bloch)	Green tail snakehead
Channa micropeltes (Cuv.)	Giant snakehead

Table 3. Some aspects of fish stocking program in irrigation reservoirs of Surin Province, Thailand during 2002-2006.

Common name	Scientific name	Average numbers stocked	Production 2006 (kg)	Income in 2006 (Thai Baht)
Tilapia	*Oreochochromis niloticus*	105,233	4,805.5	192,220
Walking catfish	*Clarias macrocephalus*	115,000	269.8	13,488
Silver barb	*Barbonymus gonionotus*	232,800	697.7	24,418
Siamese mud carp	*Henicorhynchus siamensis*	135,000	1,848.0	46,199
Suchi catfish	*Pangasianodon hypophthalmus*	95,000	96.6	3,864
Common carp	*Cyprinus carpio*	123,000	29.8	1,490
Rohu	*Labeo rohita*	90,000	53.6	2,680
Mrigal	*Cirrhinus cirrhosus*	130,000	23.3	1,165
Tinfoil barb	*Barbodes schwanenfeldi*	196,000	29.8	1,192
Giant freshwater prawn	*Macrobrachium roesenbergii*	2,475,320	170.4	38,180
Spot pangasius	*Pangasius larnaudii*	510	84.5	3,380
Mad barb	*Leptobarbus hoeveni*	12,000	NA	NA
Hybrid catfish	-	82,000	NA	NA
Barb	*Poropuntius bantamensis*	68,000	NA	NA
Carp	*Thynnichthys thynnoides*	150,000	NA	NA
Mekong giant catfish	*Pangasianodon gigas*	419	NA	NA
Red tailed tinfoil	*Barbonymus altus*	50,000	NA	NA

Queen Sirikit. In Thailand, fish stocking is done annually, usually during the month of April, since the start of rainy season and the national fisheries day on 12th April. De Silva and Funge Smith (2005) estimated that nearly 100 million of fingerlings of various species are stocked annually but the return is less than 1 percent, especially the exotic stocked species, and that they do not show a significant contribution to the catches.

Cage culture

The development of cage and pen culture, especially in Asia, has substantially increased reservoir fish production (Petr, 2007). In Thailand, cage culture is recognised as one of the important activities in lakes and reservoirs, and can be traced back to 1950 (Thanasomwang *et al.*, 1983). However, cage culture in reservoirs brings about competition with other reservoir uses, particularly fishing, navigation space and water. The cage culture practices in Thailand is semi-intensive to intensive with use of artificial feed (Lin and Kaewpaitoon, 2000). Popular species such as Nile tilapia, red fin bagrus *Hemibagrus wyckioides*, black eye shark catfish *Pangasius larnaudii* and Bocourt shark catfish *Pangasius bocourti*, are cultured in cages to marketable sizes. Also, there has been an attempt to cage culture of broodstock of African catfish *Clarias gariepinus* and hybrid catfish (Chabjinda and Teanchareon, 1991).

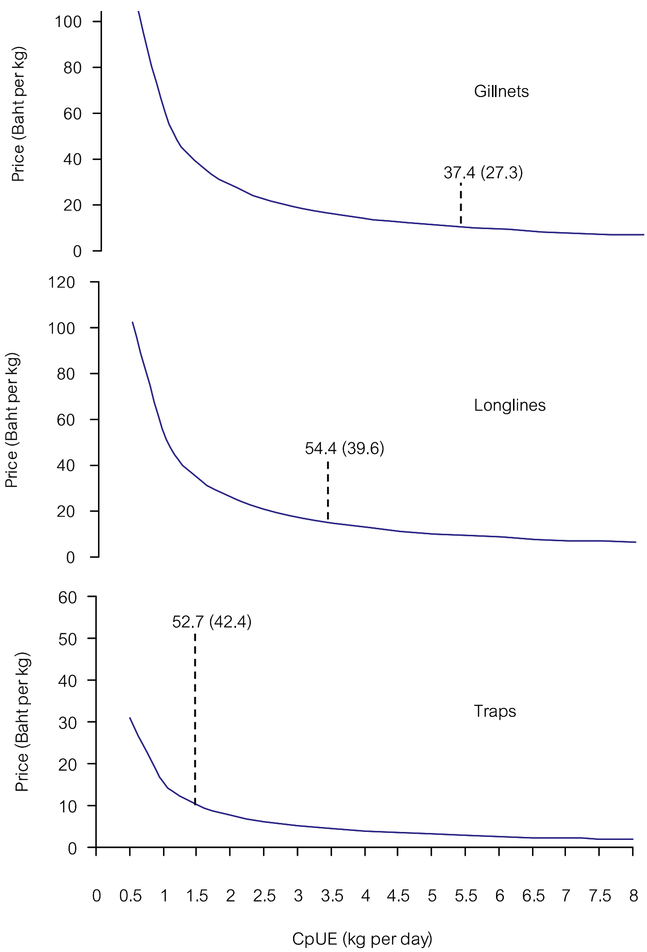
Although Sihapitukgiat *et al.* (2000) showed that growth performance, production and economic return of the cage culture in the river systems were better than in reservoirs, cage culture in reservoirs is still profitable compared to other agricultural activities. Many of the studies on cage culture in reservoirs were carried out to determine optimum stocking densities of various species (e.g. Chabjinda, 1996; Sriwatana and Kasisuwan, 1996), appropriate feed formulae for cultured fish (e.g. Thawornnan and Sorasit, 1997; Sirichaipun *et al.*, 2001) and impacts of wastes from cage culture on reservoir water quality (Sihapitukgiat *et al.*, 2000; Jiwyam and Chareontesprasit, 2001).

Socio-economics aspects

It was demonstrated that the financial income generated by the fishery in Ubolratana reservoir might be higher than that of electric power generation which was the primary objective for the impounding (Bhukaswan, 1985). In Thai reservoirs the fishery activities are exclusively the domain of males whereas females have almost exclusive responsibility for cleaning and processing of fish at landing sites and elsewhere. The catches are mostly sold in local markets and smaller catches are always taken for household consumption or processing into fermented fish.

Sihapitukgiat *et al.* (2002) mentioned that a subsistence-oriented fisher commonly has two or three income sources, most commonly also rice cultivation and/or wage labour in rice fields or non-agricultural work. Generally, poor fishers with multiple income sources fish only seasonally, but some who can spare time, fish all year round, for example setting their gillnets after work and lifting them before work next morning. In terms of income, a recent study showed that at the equilibrium stage, high profits were derived from fishing activities as 42.2, 39.6 and 27.3 Baht kg^{-1} from the trap, longlines and gillnet fisheries, respectively (Figure 4, Saowakoon *et al.*, 2008) compared to 2.8 Baht kg^{-1} from the small clupeid lift net fishery (Jutagate *et al.*, 2001a).

Figure 4. Break-even curves of the selected fisheries in the man-made lakes in Surin Province. The dashed lines indicate the current situations of catch per unit effort (CpUE) and prices of each fisheries. Numbers in parentheses are the profit values.



Conflicts in reservoir fisheries

In general, except for the cage culture in the reservoirs, there are no obvious conflicts in dam construction and operation in Thailand. One exception is Pak Mun Reservoir. It was constructed damming the Mun River six km upstream to the confluence to the Mekong. A fish ladder has been incorporated, although this has been the first fish ladder in SE Asia. many studies have shown that the "combined pool and weir type" fish ladder has been unsuccessful and is performing poorly in terms of helping the fishes to move upstream (Schouten *et al*., 2000; Roberts, 2001).

As the reservoir dam acts as a barrier for upstream migration of fish species, their abundance in fisheries production in the upstream areas have declined. It was evident that at least 37 fish species had disappeared and that the fish catch declined by 60-80 percent from the upstream areas since the construction of the dam (Jutagate *et al*., 2001b). Therefore, the riparian fishers in the area, known as "Assembly of the Poor", requested the government to resolve the problem. Based on a scientific study, since 2003, the Government has implemented the opening of all sluice gates annually for four month from May to August, to allow migratory fish to move upstream so that they can complete their life cycles (Jutagate *et al*., 2003b; Jutagate *et al*., 2005a; Jutagate *et al*., 2005b).

Regulations

In Thailand, the *Fisheries Law 1947* had been enacted on the basis of freshwater fisheries, which was the leading sector at that time. Section 32 of *Fisheries Law 1947* allows Minister/Governor to issue decrees on fishery regulations. Most of current regulations are issued under this Section. Other relevant sections are Sections 6 and 7. According to Section 6, fishing grounds are divided into four types: sanctuary, auction, permission, and public areas. Section 7, under approval of the Minister, grants authority to provincial committees to announce specific fishing measures in their provinces (Sihapitukgiat *et al*., 2002). So far, the most effective measure in the inland fishery regulation has been the closed fishing season, which is set from 16th May to 15th September countrywide except in some specific areas (Table 4).

Table 4. Closed fishing seasons for the inland fisheries of Thailand.

Province (Region)	Closed fishing season
Lampoon (North)	1st June – 30th September
Lampang (North)	1st May – 31st August
Khon Kaen, Udon Thani and Nong Bualampoo (Northeast)	16th June – 15th October
Nakorn Nayok (Central)	13th April – 12th August
Pattalung (South)	1st October - 31st January
Pang Nga (South)	1st May – 31st August
Narathiwat (South)	1st September – 31st December

Destructive fishing methods such as the use of poisons and explosives are totally prohibited. For scientific purposes, these fishing methods can be practiced with permission from the Department of Fisheries (DOF). Four types of fishing gears *viz.*, luring fishery, stationary gears, beach seine and gillnets of stretched mesh sizes less than 2.5 cm are also prohibited. The DOF Fisheries Conservation Unit, of each reservoir is the authorised agency to implement the fisheries regulations including patrolling and control the fisheries (Niumnampeth, 1981).

References

Benchakarn, M., 1972. *Fish stocking in Ubolratana Reservoir. Annual Report of Ubolratana Fishery Development Unit*. National Inland Fisheries Institute, Bangkok. (In Thai).

Benchakarn, M., Nookuor, A., 1988. Increase efficiency of stocking fish in the fingerling of rohu by pen culture in Ubolratana Reservoir. *Annual Report, Ubolratana Reservoir Fisheries Development Station*. Department of Fisheries, Bangkok.

Bernacsek, G.M., 1997. *Large dam fisheries of the Lower Mekong countries, Report No. 97023*. Mekong River Commission, Vientiane.

Bhukaswan, T., 1985. The Nam Pong Basin (Thailand). *FAO Fishery Technical Paper*, 265. Food and Agriculture Organization of the United Nations, Rome.

Bhukaswan, T., 1987. Inland fisheries In: *Thai fisheries in the future*. SEAFDEC, Samut Prakran. (In Thai).

Bhukaswan, T., Chookajorn, T., 1988. Present status of the reservoir fisheries in Thailand In: De Silva S.S. (ed.). *Reservoir Fisheries Management and Development In Asia*. Interntional Development Research Center, Ottawa.

Chabjinda, K., 1996. Cage culture of channel catfish (*Ictalurus punctatus*) in reservoir. *Technical Paper No. 40/1996*. Inland Fisheries Division, Department of Fisheries, Bangkok. (In Thai).

Chabjinda, K., Teanchareon, P., 1991. Preliminary study on cage culture of *Clarias gariepinus* in reservoir. *Proceeding of the seminar on fisheries in 1991*. National Inland Fisheries Institute, Bangkok. (In Thai).

Chookajorn, T., Leenanond, Y., Moreau, J., Srichareondham, B., 1994. Evolution of trophic relationship in Ubolratana Reservoir (Thailand) as described using a multi-species trophic model. *Asian Fisheries Science*, 7: 201-213.

Coates, D., 2002. Inland capture fishery statistics of Southeast Asia: current status and information needs. FAO RAP Publication 2002/11. Food and Agriculture Organization of the United Nations, Bangkok.

De Silva, S.S., Amarasinghe, U.S., 1996. Reservoir fisheries in Asia In: De Silva S.S. (ed.) *Perspectives in Asian fisheries: a volume to commemorate the 10th anniversary of the Asian Fisheries Society*, pp. 189-216. Asian Fisheries Society, Manila.

De Silva, S.S., Funge-Smith, S., 2005. A review of stock enhancement practices in the inland water fisheries of Asia. *FAO RAP Publication 2005/12*. Food and Agriculture Organization of the United Nations, Bangkok.

De Silva, S.S., Moreau, J., Amarasinghe, U.S., Chookajorn, T., Gurrero, R.D., 1991. A comparative assessment of the fisheries in the lacustrine inland waters in three Asian countries based on catch and effort data. *Fisheries Research* 11: 177-189.

Department of Fisheries, 2007. *Fisheries statistics of Thailand*. Available at http://www.fisheries.go.th/it-stat/.

Department of Pollution Control, 2003. *Study on the measures and mitigation to reduce impacts of freshwater fish cage culture*. Department of Pollution Control, Ministry of Natural Resources and Environment, Bangkok. 170 pp. (In Thai).

Duangswasd,i M., Janesirisak, S., 1973. *Fish stocking in Ubolratana Reservoir. Annual Report of Ubolratana Fishery Development Unit*. National Inland Fisheries Institute, Bangkok. (In Thai).

Hogan, Z.S., 2004. Threatened fishes of the world: *Pangasianodon giga*s Chevey, 1931 (Pangasiidae). *Environmental Biology of Fish*, 92: 120.

Jiwyam, W., Chareontesprasit, N., 2001. Cage culture of Nile tilapia and its loadings in a freshwater reservoir in Northeast Thailand. *Pakistan Journal of Biological Sciences* 4 (5): 614-617.

Juatagate, T., De Silva, S.S., Mattson, N.S., 2001a. Socio-economic status of river sprat (*Clupeichthys aesarnensis* Wongratana 1983) lift net fishers in Sirinthorn Reservoir, Thailand In: De Silva S.S. (ed.) *Reservoir and Culture-Based Fisheries: Biology and Management*. ACIAR Proceedings No. 98. Australian Centre for International Agricultural Research, Canberra.

Jutagate, T., Lamkom, T., Satapornwanit, K., Naiwinit, W., Petchuay, C., 2001b. Fish species diversity and ichthyomass in Pak Mun Reservoir, five years after impoundment. *Asian Fisheries Science*, 14: 417-425.

Jutagate, T., Mattson, N.S., Moreau, J., Srichareondham, B., Kumsri, M., 2002. Trophic models of Sirindhorn and Nam Ngum Reservoirs: a comparison. *Kasetsart University Fishery Research Bulletin*, 24: 1-4.

Jutagate, T., Mattson, N. S., 2003. Optimizing fishing gear operation in Sirinthorn Reservoir, Thailand. *Natural History Bulletin of the Siam Society*, 51(1): 105-122.

Jutagate, T., De Silva, S.S., Mattson, N.S., 2003a. Yield growth and mortality of Thai river sprat *Clupeichthys aesarnensis* in Sirinthorn Reservoir, Thailand. *Fisheries Management and Ecology*, 10: 221-231.

Jutagate, T., Krudpan, C., Ngamsnae, P., Payooha, K.,Lamkom, T., 2003b. Fisheries in the Mun River: a one-year trial of opening the sluice gates of the Pak Mun Dam, Thailand. *Kasetsart Journal of Science and Technology*, 37: 101-116.

Jutagate, T., Krudpan, C., Ngamsnae, P., Lamkom, T., Payooha, K., 2005a. Changes in the fish catches during the trial of opening the sluice gates of a run-of-the river reservoir in Thailand. *Fisheries Management and Ecology*, 12: 57-62.

Jutagate, T., Lamkom, T., Grudphan, C., Ngamsnae, P., Payooha, K., 2005b. Multivariate analysis in upstream migration of pangasiids and silurids from the Mekong River into the Mun River, Thailand. *Journal of Ubon Rajathanee University*, 7: 45 - 68.

Lin, C.K., Kaewpaitoon, K., 2000. An overview of freshwater cage culture in Thailand. In: Lin, C.K. and Liao, I.C. (eds.). *Proceedings of the First International Symposium on Cage Aquaculture in Asia*. Asian Fisheries Society, Manila, the Philippines.

Manosroi, A., Meng-Umphan, K., Manosroi, J., 2003. Annual sex hormonal profiles, gonad development and age determination of the Mekong giant catfish (*Pangasianodon gigas*, Chevey). *Aquaculture Research*, 34: 1379-1385.

Mitaura, H., Mitsunaga, Y., Arai, N., Yamagichi, Y., Khachaphichat, M., Viputhanumas, T., 2005. A review of the Mekong giant catfish tracking project (MCTP) from 2002 to 2004 In: *Proceedings of the 2nd International Symposium on SEASTAR2000 and Asian Bio-logging Science*. Graduate School of Informatics, Kyoto University.

Moreau, J., De Silva, S.S., 1991. Predictive fish yield models for lakes and reservoirs of the Philippines, Sri Lanka and Thailand. *FAO Fisheries Technical Paper*, 319. Food and Agriculture Organization of the United Nations, Rome.

Moreau, J., Lek, S., Leelaparata, W., Srichareondham, B., Villaneuva, M. C., 2004. A comparison of various fitting techniques for predicting fish yield in Ubolratana Reservoir (Thailand) from a time series data In: Lek, S., Scardi, M., Verdonchot, P.F.M., Descy, J.P. and Park, Y.S. (eds.) *Modelling Community Structure In Freshwater Ecosystem*s. Springer, Berlin.

Niumnampeth, W., 1981. *Fisheries law and regulations*. Department of Fisheries, Bangkok.

Pawaputanon, O., 1988. Study of determine the most effective size of seed fish for stocking in public water. *Technology and Production Plan No. 2/1986, Northeast Fishery Project*. Department of Fisheries, Bangkok. (In Thai)

Pawaputanon O. 1992. Inland capture fisheries in Thailand. *FAO Fisheries Report* No. 458, Supplement. Food and Agriculture Organization of the United Nations, Rome.

Petr, T. 2007. Intensification of Reservoir Fisheries in Tropical and Subtropical Countries. *International Review of Hydrobiology*, 79: 131-138.

Pholprasit, S., Waiwuttho, N., 1970. Stocking of Chinese carps in Ubolratana Reservoir In: *Annual Report of Ubolratana Fishery Development Unit*. National Inland Fisheries Institute, Bangkok. (In Thai).

Prchalová, M., Draštík, V., Kubecka, J., Sricharoendham, B., Schiemer, F., Vijverberg, J., 2003. Acoustic study of fish and invertebrate behavior in a tropical reservoir. *Aquatic Living Resources*, 16: 325–331.

Prompoj, W., 1994. *Planning for sustainable reservoir fisheries in Thailand*. Ph.D. Thesis, University of Waterloo, Ontario.

Roberts, T.R., 2001. On the river of no returns: Thailand's Pak Mun Dam and its fish ladder. *Natural History Bulletin of the Siam Society*, 49: 189-230.

Satapornwanit, K.,Wongrat, P., 2000. Inland fisheries resources of Thailand In: *Proceedings of the 12th Asian Agriculture Symposium "Agriculture and Water"*. Kyushu Tokai University, Kyushu.

Saowakoon, S., Boonjung, H., Ngamsnae, P., Jutagate, T., 2008. Financial analysis of the professional fisheries in the man-made lakes in Surin Province, Thailand. *Paper presented at the 49th Kasetsart University Annual Conference*, February 2008. Bangkok, Thailand.

Schiemer, F., Amarasinghe, U., Frouzova, J., Sricharoendham, B., Silva E.I.L., 2001. Ecosystem structure and dynamics—a management basis for Asian reservoirs and lakes. In: De Silva S.S. (ed.) *Reservoir and Culture-based Fisheries: Biology And Management*. ACIAR Proceedings No. 98. Australian Centre for International Agricultural Research, Canberra.

Schouten, R., Sripatraprasit, P, Amornsakchai, S., Vidthayanon, C., 2000. *Fish and fisheries up- and down-stream of the Pak Mun Dam*. World Commission on Dams, Cape Town.

Sidthimunka, A., Potaros, M., Boonsom, J., Pawaputanon, O., 1978. Observations on the hydrology and fisheries in Ubolratana Reservoir. *Technical Paper of the Inland Fisheries Division*, Department of Fisheries, Bangkok. 40 pp. (in Thai).

Sihapitukgiat, P., Srichareontham, B., Kittivorachate, R., Ingthamchit, S., Chittapalapong, T., 2000. Growth performance, production model, environmental impact and economics of commercial Nile tilapia cage culture in Northeast of Thailand. *Technical paper No. 204*. National Inland Fisheries Institute, Bangkok. (In Thai).

Sihapitukgiat, P., Junsawang, B., Srichareontham, B., Ingthamchit, S., Chittapalapong, T., Su-a-run, K., Ratanachumnong, D., Kakkaew, M., Boonchuwong, P., Sidthimunka, C., Noradee, P., 2002. *Limnological, fisheries and socio-economical characteristics of Ubonratana Reservior, Khon Kaen, Thailand*. National Inland Fisheries Institute, Bangkok.

Sirichaipun,N., Manee, M., Janesirisak, S., 2001. Production of Nile tilapia rearing difference feeding regimes in Sirindhorn Reservoir. *Technical paper No. 17/2001*. Inland Fisheries Division, Department of Fisheries, Bangkok. (In Thai).

Sirimongkolthaworn, R., 1999. The biology and feeding of freshwater sardine *Clupeichthys aesarnensis* in Ubolratana Reservoir, Thailand. M.Sc. thesis, University of Waterloo, Canada.

Srichareondham, B. Leelapatra, W., Rattanachamnong, D., Kaewjaroon, P., Aimsab, M., 2000. Variation on fish community and catch of Siridhorn Reservoir, Ubon Ratchathani Province. *Technical paper* No. 206. National Inland Fisheries Institute, Bangkok. (In Thai).

Sriwatana, W., Kasisuwan, S., 1996. Effects of stocking densities on growth and yield of the green catfish *Mystus nemurus* (Cul. & Val.) cultured in floating cages. *Technical Paper No. 30/1996*. Pattani Inland Fisheries Development Centre, Department of Fisheries, Thailand. (In Thai).

Thanasomwang, W., Tewaratmaneekul, P., Viputhanumas, T., Kongphol, C., 1983. Cage culture in Thailand. *Extension Paper No. 1/1983*. Department of Fisheries, Bangkok. (In Thai).

Thappanand, T., Moreau, J., Jutagate, T., Wongrat, P., Lekcholayut, T., Meksumpun, C., Janekitkarn, S., Rodloi, A., Wongrat, L., 2008. Trophic relationship and ecosystem in the newly impounded man-made lake in Thailand. *Fisheries Management and Ecology* (In press).

Thawornnan, W., Sorasit, S., 1997. Experiment on cage culture of giant gorami *Osphronemus gorami* Lacepede in Bung Sifai, Pichit. *Technical Paper No. 8/1997*. Inland Fisheries Division, Department of Fisheries. (In Thai).

TDRI, 1987. *Thailand natural resource profile: Is the resource base for Thailand's development sustainable?* Thailand Development and Research Institute (TDRI), Bangkok.

Verdegem, M.C.J., 1999. Lakes and reservoirs in Indonesia, Malaysia, the Philippines, Singapore and Thailand In: van Densen, W.L.T. and Morris M.J.

(eds.) *Fish and Fisheries of Lakes and Reservoirs In Southeast Asia and Africa*. Westbury Publishing, Otely.

Vidthayanon, C., Karnasutra, J.,Nabhitabhata, J., 1997. *Diversity of freshwater fishes in Thailand*. Office of Environmental Policy and Planning, Bangkok.

Virapat, C., 1993. *Bionomics of fish stocking in two Thai reservoirs; biological, management and development perspectives*. Ph.D. thesis, Dalhousie University, Nova Scotia.

Virapat, C., Mattson, N.S., 2001. Inventory of reservoir fishery resources in Thailand In: De Silva S.S. (ed.) *Reservoir and Culture-based Fisheries: Biology and Management*. ACIAR Proceeding No. 98. Australian Centre for International Agricultural Research, Canberra.

Virapat, C., Phimonbutra, U., Chantarawaratid, C., 2000. *Fishery and Fisheries Management in Thai Reservoirs*. Review and Assessment. Management of Reservoir Fisheries in the Mekong Basin. Mekong River Commission, Vientiane.

Yamagichi, Y., Mitaura, H., Arai, N., Yasushi, M., Kawabata, Y., Khachaphichat, M., Viputhanumas, T., 2005a. Feeding habits of hatchery-reared young Mekong giant catfish in a fish pond and in Mae Peum Reservoir In: *Proceedings of the 2nd International symposium on SEASTAR2000 and Asian Bio-logging Science*. Graduate School of Informatics, Kyoto University.

Yamagichi, Y., Mitaura, H., Mitsunaga, Y., Arai, N., Khachaphichat, M., Viputhanumas T., 2005b. Study on feeding habits of Mekong giant catfish in Mae peum Reservoir, Thailand In: *Proceedings of the 2nd International symposium on SEASTAR2000 and Asian Bio-logging Science*. Graduate School of Informatics, Kyoto University.

www.enaca.org