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Reservoir Fishery Management and Development in Asia

Proceedings of a Workshop held in Kathmandu, Nepal, 23-28 November 1987

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ABSTRACT

This publication presents the results of an IDRC-funded workshop held in Kathmandu, Nepal, 23-28 November 1987. Representatives from 15 countries reviewed the status of reservoir fishery research in Asia under the following topics: existing fisheries, limnological aspects, biological and resource aspects, management aspects, and culture. Papers were presented on these topics, but the discussion sessions were the main element of the workshop. Summaries of these discussions as well as a series of general recommendations that were generated during the final discussion are presented in this book. The potential for increased fish production in reservoirs and the need for early involvement of fisheries scientists in the planning and preimpoundment studies before dam construction are emphasized.

RÉSUMÉ

Cet ouvrage présente les résultats d'un atelier financé par le CRDI à Katmandou, au Nepal, du 23 au 28 novembre 1987. Des représentants de 15 pays ont examiné l'etat de la recherche sur l'élevage du poisson en étangs en Asie, en particulier les aspects suivants : les systèmes actuels, les aspects limnologiques et biologiques, les ressources, la gestion et l'élevage. Des exposés ont été présentés sur ces sujets, mais les discussions ont été l'élément le plus important de l'atelier. L'ouvrage présente également un résumé des discussions ainsi que les recommendations générales issues de ces discussions. On met l'accent sur la possibilité d'augmenter la production de poissons en étangs et la nécessité pour les ichtyologistes de participer trés tôt aux études de planification, notament de la mise en étangs du poisson, qui précèdent la construction d'un barrage.

RESUMEN

Esta publicación presenta los resultados de un taller auspiciado por el CIID en Kathmandu, Nepal, del 23 al 28 noviembre de 1987. Representantes de 15 países analizaron el estado de la investigación sobre pesquería asiática en embalses desde los siguientes ángulos: pesquería existente, aspectos lomnológicos, aspectos biológicos y de recurso, aspectos de manejo y cultivo. Las ponencias versaron sobre estos temas, pero las sesiones de discusión fueron el principal elemento del taller. Este libro ofrece los resúmenes de estas discusiones, así como una serie de recomendaciones generales emanadas de ls discusión final. Se subraya el potencial para incrementar la producción pesquera en embalses y la necesidad de una participación temprana de los científicos del área en la planificación y los estudios de apropiación que anteceden a la construcción de represas.

CONTENTS

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The International Development Research Centre (IDRC) wishes to acknowledge the kind assistance of the Fisheries Development Section, Ministry of Agriculture, His Majesty's Government of Nepal, in making the local arrangements for the workshop and the field trip to Pokhara, and the Department of Agriculture, Ministry of Agriculture and Community Development, Kuching, Sarawak, Malaysia, for their additional financial support. IDRC also wishes to recognize the major contribution of Dr Sena S. De Silva in arranging the sessions, participants, and, with assistance from Dr John F. Craig, in editing the papers. IDRC thanks the following participants for chairing and summarizing the discussions of the individual sessions: J.F. Craig, R.D. Guerrero III, A. Duncan, A. McNaughton, B. Pradhan, Li Sifa, J. Vijverberg, D.E.M. Weerakoon, F. Schiemer, U.S. Amarasinghe, M. Beveridge, Yap Siaw-Yang, R.C. Sharma, and Sena S. De Silva.

FOREWORD

The Fisheries Program of the Agriculture, Food and Nutrition Sciences Division of the International Development Research Centre (IDRC) focuses its support primarily in the sectors of aquaculture and artisanal fisheries. In the Asian region, these two sectors are important in reservoir fisheries management and development. Reservoir construction in Asia is increasing rapidly, with many countries projecting massive increases in their reservoir surface area by the year 2000. At present, however, there is a very limited research and data base on which to make sound planning and development decisions.

IDRC has been supporting some projects on reservoir development and is now examining a possible expansion in this area. Many scientists and research institutions in the Asian region have expressed concern about the present state of knowledge and a desire for future support on this topic. Also, because reservoir fisheries is relatively new in Asia, there was considerable interest among scientists working on Asian reservoirs to meet and exchange research results and discuss future strategies for research and development. With these points in mind, IDRC agreed to sponsor a workshop on reservoir fishery management and development in Asia with the following objectives:

- to evaluate the work to date in the region on Asian reservoir fishery management;
- to plan future stategies for research leading to the effective management of reservoirs; and
- to encourage the consideration of fisheries aspects at the time of reservoir-development planning.

Many countries in the Asian region have already recognized the major potential for increased fish production from reservoirs. These bodies of water are one of the few new sources of potential fish production in the world. Nepal, the host country for this workshop, is one example. The staff of the Fisheries Development Section, Ministry of Agriculture, His Majesty's Government of Nepal, with IDRC support, is now conducting a systematic study on reservoir fisheries development in the 220-ha Indrasarobar Reservoir on the Kulekhani River. There are now only a few reservoirs in Nepal (surface area, approx. 1500 ha); however, by the year 2000, over

200,000 ha of water surface area will have been created. Clearly, research and planning on reservoir fishery management and development will have a great impact on the future of Nepal and many other countries in the Asian region.

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INTRODUCTION

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The reservoir area in Asia, including mainland China, is increasing significantly from its present level of approximately 5.5×10^6 ha. The utilization of the reservoir for fish production is relatively recent, especially when compared with the traditional aquaculture practices in the region. In most countries in Asia, the reservoirs now contribute significantly to the total inland fish production. There is also a trend toward the utilization of reservoirs for intensive to semiextensive aquaculture, at times resulting in conflicting interests.

This workshop on reservoir fishery management and development in Asia brought together 31 participants from 15 countries who are involved in fisheries studies on Asian reservoirs. The proceedings encompasses the papers presented and the discussions held at the workshop and is divided into five sections: Existing Fisheries, Limnological Aspects, Biological and Resource Aspects, Management Aspects, and Culture. These divisions were made not only on the basis of the nature of the presentations but also with a view to facilitating the discussions that were to follow.

The section on existing fisheries briefly dealt with the existing reservoir capture fisheries in some of the countries and a review of Asian reservoir fisheries, including mainland China, and is followed by the section on limnological aspects. The paucity of limnological research, particularly in relation to fisheries, on Asian reservoirs is apparent from the number of presentations that were made.The distinction made in the following two sections (Biological and Resource Aspects, and Management Aspects) is more for convenience than for any scientific reasoning; in effect, one runs into the other. In these two sections, the resource and management problems and resource optimization of reservoir fisheries are focused upon from a number of viewpoints, including ecosystem and dynamic, holistic approaches. The last section deals with the use of the reservoir resource for fish culture.

It is hoped that this volume will provide some basic information on the ongoing research related to the management and development of the reservoir fisheries in Asia, which forms a significant component of the inland fish production as a whole in the region. The final and individual summaries of the discussions that followed each section were essentially expected to highlight the research strategies that would lead to the optimization of fish yields from the vast reservoir resource in the region.

Although reservoir fisheries is important to most countries in the region in providing a relatively low-priced, good-quality protein source and occupational opportunities, the scientific literature available on reservoir fisheries in the region is relatively scarce. It is hoped that this book will help to close this gap in our knowledge and, most af all, to sow a seed in the the direction of optimizing the use of the reservoir resource for fish production.

INAUGURAL ADDRESS

Hari Narain Rajouria

Honourable Minister for Agriculture, Law and Justice,
His Majesty's Government of Nepal

Distinguished participants, ladies and gentlemen. I am indeed pleased and honoured to have been invited to inaugurate this important workshop being held in Kathmandu and for this I wish to express my thanks to the organizers. On behalf of His Majesty's Government and myself, I would also like to express sincere thanks to the International Development Research Centre for selecting Nepal as the venue for this workshop. It is my pleasure to welcome all the distinguished participants to the ancient city of Kathmandu. Although your stay will be a short one, I hope you will all find enough time to visit and explore Kathmandu from both historical and cultural perspectives. I wish you a pleasant and memorable stay.

Like many of the least-developed countries of the world, Nepal's economy is predominantly based on agriculture. Nearly 90% of the population derives their livelihood from this sector and about 95% of the population lives in rural areas. Two-thirds of the area of Nepal is covered by rugged mountains. This mountainous sector is characterized by small farms, small-scale fishermen, and landless agricultural labourers.

Forestry, tourism, and water are the major resources of Nepal. In fact, the per capita water availability of Nepal is second in the world only to Brazil. However, because Nepal is a landlocked country, 1000 km away from the nearest ocean, economic development to alleviate the poverty of the people is difficult. There are many ways of exploiting and harvesting these abundant water resources. Some are highly capital-intensive and have a long gestation period; others do not. Fishery development with sustainable and appropriate technology will not only supply animal protein to the people but also provide employment and income opportunities to many small-scale farmers, fishermen, and landless agricultural labourers.

Because Nepal is a landlocked country, we must exploit the abundant inland water resources for fish production. Although our involvement in organized, scientific, inland fish-culture development is relatively modest and recent, the progress made to date provides much promise. We believe much can be done with the available resources of the country.

Our first effort in fishery development was an aquaculture-development project in the southern plains and inner valleys of the country. Substantial progress has been made in generating appropriate technology for pond fish culture, in particular, which has benefited the small-scale farmer. The expansion and intensification of pond fish culture, however, have some limitations. Therefore, we must also explore the area of riverine fish culture. Not much progress can be made in this area, however, because of resource constraints.

There are about 6000 rivers forming three major river systems in Nepal: Koshi, Karnali, and Gandaki. These river systems make up a waterway with a total length of 21,000 km. In our endevours to exploit this potential, His Majesty's Government has identified about 60 potential dam sites for hydro-electric power generation, flood control, and irrigation, These rivers, once dammed, will create about 238,000 ha of reservoirs. Therefore, it is evident that there is much potential for the development of reservoir fisheries in Nepal.

Nepal has now begun the massive task of fulfilling the basic needs of all its people by the year 2000 in accordance with the noble wish of His Majesty the King, Birendra Bir Bikram Shah Dev. Because food is the most important of the basic needs, food-production programs have been formulated. Fish being an important food item and source of animal protein, one of the main challenges ahead of us is to develop appropriate strategies for an aquaculture-development program. Accordingly, stategies are being adopted to make better use of fish ponds and to tap the benefits of riverine fisheries. Some of the countries of the region have very effective programs and experience on reservoir fisheries. I hope this workshop will provide an opportunity for the Nepalese participants to share in these experiences. I also hope that the deliberations and exchanges of experience and information in this workshop will provide new insights in our efforts for the development of reservoir fisheries in the region.

I wish you all much success in your deliberations and meaningful conclusions to the workshop. Thank you.

SUMMARY AND RECOMMENDATIONS

Information Transfer

There is a need for more information exchange between "reservoir fishery developed" and "reservoir fishery developing" countries. Because of language differences, translating key reviews is recommended. Improved information transfer should be aimed at scientists, planners, and involving users. Participants recommended that utilizing existing mechanisms, such as available newsletters and societal and institutional publication systems, be emphasized. Further details are provided in subsequent recommendations.

Reservoir Classification

Predictive Index

Development of a more appropriate predictive index for yield estimation in Asia was suggested. This is particularly needed as large, external nutrient loaded reservoirs are common.

Models

The meeting also addressed the question of making a distinction between culture and capture fisheries in reservoirs. The concensus was that those "systems" that depend on continuous stocking and harvesting, irrespective of their intensity, should be considered reservoir culture fisheries.

The workshop agreed that the most effective management practice to be adopted for optimizing yield would have a bearing on the development of a meaningful classification of the reservoir for management purposes. This classification would be based on a variety of characteristics ranging from morphometry to limnology. Yield models for freshwater reservoir multispecies fisheries are also needed.

User Participation

Documentation on the present status of management systems and the role of fishermen and their various means of orginization (e.g., societies, cooperatives) is needed. This could also be particularly important in terms of documenting impacts on displaced persons following reservoir inundation. More effective participation by these affected groups in the fishery-development process is clearly needed.

The Indonesian model of involvement in aquaculture of the displaced persons from the inundated area was taken as a good example. The Indonesian scientists hope soon to have a paper in English produced from their data, which is now available in Indonesian.

Importance of Fisheries

Fisheries has been shown to be an important food- and income-producing activity in many Asian reservoirs. More effective and earlier involvment of fisheries scientists in reservoir planning can further optimize the production.

Research

More detailed scientific studies in various aspects of reservoir limnology and fisheries biology are suggested in the individual session discussion summaries. A holistic approach based on ecosystem evaluation is necessary, particularly when considering indigenous versus exotic species. Little research has taken place on a more varied system and methods of fish harvesting, particularly for nonconventional fish species. The many experiences of China in this regard were noted. Simple equipment (e.g., kits) for many standard measurements in limnology are needed. More information in the form of manuals on routine methods was also recommended.

Future Meetings

All participants felt there was not enough interactions to date among Asian reservoir scientists and this meeting was an important step in promoting more information transfer. The possibility of having future meetings and the establishment of an Asian Reservoir Fishery Research Network was discussed.

Session I

Existing Fisheries

THE PRESENT STATUS OF THE RESERVOIR FISHERY IN INDONESIA

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Abstract *Three types of reservoirs exist in Indonesia: field, irrigation, and multipurpose. The annual production of fish in these reservoirs varies from 15 to 380 kg/ha. Capture fisheries are dominant in Indonesian reservoirs. Stocking programs have been managed by the government to sustain fish yields. Fish culture practices, conducted mainly in floating net enclosures, have been recently introduced in the Lido, Saguling, and Riam Kanan reservoirs and the natural lake Toba. Common carp (Cyprinus carpio) is the most important species cultured. Fish culture has shown good potential and should be pursued in the future. Physical and chemical characteristics of some major Indonesian reservoirs are outlined in the paper.*

Indonesia has three types of reservoirs: field, irrigation, and multipurpose (Table 1). Field reservoirs satisfy the water needs of the local community. In certain areas, these reservoirs act as water traps for the conservation of ground water. They are built by damming creeks or diking valleys. Irrigation reservoirs supply water for agricultural purposes. They are built by damming relatively small rivers. Multipurpose reservoirs are created for flood control, hydroelectric power generation, irrigation, and to supply water for industrial and municipal purposes. They are built by damming relatively large rivers.

Open-water fisheries, including reservoir fisheries, has an important role in Indonesia contributing 270,000 t to the total freshwater fish production (Anon. 1987). There is no specific data on the total fish production of all the reservoirs in Indonesia; however,

Table 1. Types of reservoirs in Indonesia.

Type	Size (ha)	Depth (m)	Authority
Field	20	5	Community
Irrigation	20-500	5-30	Local government
Multipurpose	500	30-100	Central government

the average annual production per hectare of some reservoirs is known (Table 2). The total area of reservoirs and natural lakes are about 1.8×10^6 ha, of which at least 53,000 ha is reservoirs.

Table 2. The major reservoirs of Indonesia and their characteristics.

Reservoir	Purpose[a]	Volume (x 10^6 m^3)	Area (km^2)	Drawdown (m)	Annual fish yield (kg/ha)	Fish species[b]
			West Java			
Darma	I	40	4.0		270	T,C,L
Lido	I		0.3			T,C,L
Jatiluhur	F,E,I	2970	83.0	32.0	15	T,C,L,H,S, P,M
Saguling	E	982	53.4	20.0		T,C,L,J,S, M
Cirata	E	2165	62.0	20.0		
			Central Java			
Cacaban	I	86				
Sempor	E,I	52		29.0		
Wonogiri	F,E,I	736	90.0	9.0		T,C,L,H,S, P
Wadaslin-tang[c]	E,I	443	14.6	61.0		
Kedung Ombo[c]	E,I	723	46.0	25.0		
			East Java			
Prijetan	I	10	2.2		50	
Pacal	I	41	4.5		380	
Selorejo	F,E,I	62	4.0	24.0	250	T,C,L,P,S
Karang-kates	F,E,I	343	15.0	26.0	50	T,C,L,H,M, S
Lahor	E,I	37	2.6	19.0	50	T,C,L,H,S, M
Wlingi	E,I	24	3.8	1.5	25	
Bening	E,I	37	5.7	12.0	150	T,L,S
Wonorejo[c]	E,I	122	3.8	42.0		
			Lampung (Sumatera)			
Way Jepara	I	50				
Way Rarem	I	72		6.8		
			South Kalimantan			
Riam Kanan	F,E,I	1200	92	8.0		T,C,L,H,S,M

(continued)

Table 2. Concluded.

Reservoir	Purpose[a]	Volume (x 10^6 m^3)	Area (km^2)	Drawdown (m)	Annual fish yield (kg/ha)	Fish species[b]
			West Nusa Tenggara			
Batujai	I	17	8.9	5.0		

[a]I, irrigation; F, flood control; E, electricity.
[b]T, Tilapia mossambica and Tilapia nilotica; C, common carp (Cyprinus carpio); L, lampam (Puntius gonionatus); H, hampala (Hampala macrolepidota); S, snakehead (Ophicephalus seriatus); P, pangasius (Pangasius pangasius); M, macrones (Macrones nemurus).
[c]Reservoir under construction.

Capture fisheries is dominant in Indonesian reservoirs, involving about 434,000 people. At least 34 fish species have been recorded, including the economically important species listed in Table 2. Fishing gear varies, ranging from static fish traps to floating gill nets. In certain areas, hook and lines, cast nets, or lift nets are also used.

Stocking programs, managed by the government, are also practiced. During the high-water period (rainy season), fingerlings of commercially important species such as common carp (Cyprinus carpio), lampam jawa (Puntius javanicus), and Nile tilapia (Oreochromis niloticus), are released into reservoirs. Mature fish are harvested during the low-water period (dry season). Any failure in a stocking program can usually be attributed to one or a combination of the following factors: unfavourable water quality, severe competition with indigenous species, high predation pressure by carnivorous species, prohibitive condition for fish development (e.g., unfavourable spawning grounds or habitat), or disturbance by the surrounding human community.

Reservoir fish culture is practiced in pens, cages, and floating nets. Pen culture is conducted in water less than 3 m deep; cage and net culture are practiced in deeper water. Floating-net culture has recently begun in the Saguling, Lido, and Riam Kanan reservoirs and in the natural lake Toba cultivating mainly common carp. In the Saguling Reservoir, there are now about 600 7 m x 7 m floating nets in operation. A stocking density of about 300 kg fish/net can produce 1.0-1.5 t of fish in a 3-month rearing period (Costa-Pierce et al., this volume; G. Wiraatmadja, personal communication) with food-conversion rates (commercial pelleted feed) varying from 1.5 to 2.0.

Many studies have examined various physical and chemical properties of the major reservoirs of Indonesia. The results for the Saguling, Jatiluhur, Pacal, Wonogiri, and Riam Kanan reservoirs are summarized in Table 3.

Table 3. Physical and chemical properties of five major reservoirs in Indonesia.

	Saguling	Jatiluhur	Pacal	Wonogiri	Riam Kanan
Temperature (°C)	23.0-29.0	28.2-30.5	27.0-34.0	26.0-29.0	28.0-29.5
Secchi disk transparency (cm)	80-240	26-230	129	-	220-300
Turbidity	11-62	3-300	-	68-350	-
Conductivity (µmho/cm)	110-500	108-155	-	269-364	-
Total dissolved solids (mg/L)	-	-	-	81-345	-
MEI[a]	6.3-28.6	3.0-4.3	-	31.6-42.8	-
Dissolved oxygen (mg/L)	2.0-6.5	4.7-7.1	8.0-9.0	3.8-4.6	6.9-7.2
CO_2 (mg/L)	0.5-4.5	1.7-4.1	-	-	4.7-7.5
pH	4.5-9.5	7.2-8.0	6.0-8.4	6.2-8.2	6.9-8.4
Alkalinity (mg/L $CaCO_3$ equiv.)	5-60	45-67	-	44-259	56-65
Phosphate (mg/L)	0.07-0.85	0.04-0.06	-	0.28-0.90	-
Nitrite (mg/L)	0-0.09	0.01-0.15	-	-	-
Nitrate (mg/L)	0.09-3.57	0.28-0.64	-	0.11-0.92	-
Ammonium (mg/L)	0.07-0.53	0.01-0.25	-	-	-
Sulphate (mg/L)	0.39-1.47	0.87-1.63	-	-	-
Calcium (mg/L)	33-79	40-47	-	34.5-42.0	-
Hardness (mg/L $CaCO_3$ equiv.)	48-135	59-72	-	91.5-157.0	-

Source: Saguling, Kartamihardja et al. (1986); Jatiluhur, Krismono and Hardjamulia (1986) and Dhahiyat et al. (1975); Pacal, Sarnita (1976); Wonogiri, Achmad (1976); Riam Kanan, Jangkaru (1975).

[a]Morphoedaphic index (MEI) = conductivity/mean depth.

Discussion

Most of the reservoirs in Indonesia are located in the most densely populated island of Indonesia, Java. It is difficult to obtain information on reservoir fisheries because much of the information is integrated with data on lake fisheries.

Field reservoirs are the oldest type of reservoirs. At present, most of these reservoirs are heavily infested with aquatic weeds. The degree of infestation depends on the degree of maintenance of the reservoir. Sporadic fishing is common in these waters. The main fish caught of commercial value include snakehead (Ophicephalus striatus), walking catfish (Clarias batrachus), dwarf gouramies (Trichogaster trichopterus and Trichogaster pectoralis), climbing perch (Anabas testudineus), and minnows (Puntius binotatus and Rasbora spp.). In well-maintained field reservoirs, a stocking program or confined fish culture are occasionally practiced.

Irrigation reservoirs received the maximum attention of the stocking program. They are relatively free of aquatic weed infestation because they are better maintained, and they can be fully drained during the dry season (low water) for easy harvesting. Depending on the kind of stocking program, public fishing may be prohibited. Confined fish culture is sometimes conducted in these reservoirs.

Multipurpose reservoirs are given the most attention with respect to fisheries development. The potential of their vast, relatively stagnant waters as a fishery resource is high. Public fishing is the prominent activity in these reservoirs; therefore, to prevent the deterioration of the fishery resource as a result of intensive fishing activities, rules and regulations must be strictly enforced. Stocking programs in multipurpose reservoirs are conducted mainly for the manipulation or rehabilitation of the fish population. Confined fish culture is occasionally practiced.

Conclusions

Although the reservoir fishery of Indonesia contributes only a small portion of the inland fish yield, it is an important source of food (protein) for the people. Capture fisheries play a prominent role in the production effort; to maintain a sustainable yield, fishing rules and regulations must be strictly enforced. The public should be encouraged to conduct their own stocking programs; at present, stocking programs are exclusively run by the government. Confined fish culture has shown good potential and should be pursued in the future.

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THE STATUS OF RESERVOIR FISHERIES IN THE PHILIPPINES

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Abstract *The Philippines has extensive reservoir systems that are utilized for hydroelectric power generation, irrigation, and fisheries. Inland fisheries contributes 12.2% to the total fish production of the Philippines. Around 20,000 families are dependent on reservoirs for their food and livelihood. The most common fish caught in Philippine reservoirs are Nile tilapia, goby, common carp, and mudfish. Reservoir fishermen use gill nets, hooks and lines, spears, and traps for fishing. Stocking and cage culture of tilapia are also practiced. The major constraints threatening the sustainability of Philippine reservoirs are the high rate of sedimentation and overfishing. Basic studies on the productivity of the water bodies and an assessment of the impact of production-enhancement measures are needed. A multisectoral, integrated approach for reservoir fisheries management through a national coordinating action group is recommended.*

The Philippines has an extensive inland water system consisting of lakes, rivers, and reservoirs. There are seven major reservoirs in the country with a total area of 18,770 ha (Table 1). In addition, 97 small water impoundments with a total area of 523.9 ha have been constructed throughout the islands.

Although reservoirs have multiple uses, their most significant role is that of a provider of income and food for rural families. The Philippine Bureau of Fisheries and Aquatic Resources has estimated the 1985 fish production from inland municipal fisheries to be 260,300 t, or 12.2% of the country's total fish production. At least 20,000 families are believed to be dependent directly or indirectly on the fisheries resources of Philippine reservoirs (Roldan 1980).

Six of the seven major Philippine reservoirs are on the island of Luzon; the other is in Mindanao. The country's largest reservoir is in Pantabangan, Nueva Ecija, with an area of 8900 ha and a maximum depth of 28.9 m. The main uses of the reservoirs are hydroelectric power generation, water supply for irrigation, and fisheries (Table 1).

Philippine reservoirs are characteristically deep, high in elevation, and have a low diversity of endemic fish fauna (Baluyut

Table 1. Characteristics of the seven major reservoirs of the Philippines.

Reservoir (location)	Area (ha)	Elevation (m)	Maximum depth (m)	Uses	Fishing gear used	Fish caught	1986 fish production (t)[a]
Ambuklao (Bokod, Benguet)	700	1524	78	Power generation, fisheries	Gill net, hook and line, spear	Tilapia, goby, mudfish, common carp	NA
Binga (Itogon, Benguet)	150	914	40	Power generation, fisheries	Gill net, hook and line, spear	Tilapia, goby, mudfish, common carp	NA
Magat (Ramon, Isabela)	4460	1500	80.5	Power generation, irrigation, fisheries	Gill net, hook and line, fish trap	Tilapia, catfish, goby, freshwater grunt, mudfish	6726
Pantabangan (Pantabangan, Nueva Ecija)	8900	230	28.9	Power generation, irrigation, fisheries	Gill net, long-line, hook and line, spear, fish trap	Tilapia, mudfish, common carp, milkfish, catfish, eel, gourami	NA

(continued)

Table 1. Concluded.

Reservoir (location)	Area (ha)	Elevation (m)	Maximum depth (m)	Uses	Fishing gear used	Fish caught	1986 fish production (t)[a]
Angat (Norzagaray, Bulacan)	2300	102	94	Power generation, irrigation, water supply, fisheries	Gill net, long-line, hook and line, push net, fish trap	Tilapia (75% of catch), common carp, mudfish, milkfish	87
Caliraya (Lumban, Laguna)	1160	305	20	Power generation, fisheries	Gill net, hook and line, longline, spear	Largemouth bass, tilapia, common carp, mudfish, goby, freshwater grunt	NA
Pulangui IV (Maramag, Bukidnon)	1100	405	15[b]	Power generation, fisheries	Gill net, hook and line	Tilapia, common carp, rohu	2.4

[a]NA, no data available.
[b]Mean value.

1983). Except for three reservoir fisheries, there are no available fish-catch data. Commonly caught fishes include Nile tilapia (Tilapia nilotica), goby (Glossogobius giurus), common carp (Cyprinus carpio), and mudfish (Ophicephalus striatus). Aside from tilapia and common carp, other exotic fish that have been stocked in reservoirs include the milkfish (Chanos chanos), rohu (Labeo rohita), and largemouth bass (Micropterus salmoides). Reservoir fishermen have utilized gill nets, hooks and lines, spears, and traps for fishing (Table 1).

Fish-culture techniques, such as cage culture on tilapia, have been introduced into Pantabangan Reservoir (Guerrero et al. 1987) and the Magat Reservoir (MRMP 1986) to enhance fish production. The Ambuklao and Caliraya reservoirs have been stocked with largemouth bass from the United States for recreational fishing (Gracia and Magsumbol 1987). There is little or no information available on the impact of such management techniques on the endemic fish of the reservoirs and an assessment of their effects on fisheries as a whole has yet to be done.

Major Constraints Affecting Reservoir Fisheries

The major constraints threatening the sustainability of Philippine reservoirs are the high rate of sedimentation as a result of watershed erosion and overfishing as a result of the bourgeoning fishing communities along the shoreline and watershed of the reservoirs. Although reforestation measures have been adopted to forestall the rapid siltation of dams, lack of baseline information on the productivity of Philippine reservoirs has limited the effectiveness of fisheries-management programs. The socioeconomics of fishing communities depending on reservoirs is not well understood.

Conclusions and Recommendations

Fishery reservoirs play a significant role in providing income and high-protein food for an increasing number of rural families in the Philippines. Although fish-production enhancement measures have already been applied in some reservoirs, there is a lack of basic information on the impact of such practices and the natural productivity of the reservoirs. Such information is essential for the formulation of a sound fisheries-management program.

The following five recommendations for future action apply to reservoir fisheries in the Philippines.

- Basic research on reservoir productivity should be conducted.
- The socioeconomics of fishing communities dependent on reservoirs should be examined.
- Fisheries-management schemes in reservoirs such as Magat and Caliraya should be evaluated and assessed.
- A multisectoral, interdisciplinary approach in the management of reservoir fisheries should be adopted.
- A coordinating action group for reservoir fisheries management in the Philippines should be organized.

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THE RESERVOIR FISHERY OF ASIA

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Abstract *Both the natural and man-made inland water resources in Southeast Asia available for fisheries are extensive. The reservoir area alone amounts to 5.563 x* 10^6 *ha. The inland fishery of Southeast Asia accounts for nearly 57% of the total inland fish production of the world and has steadily increased over the last decade. This paper considers those countries listed under South and East Asia by the Food and Agriculture Organization fishery statistics as well as mainland China. Reservoir fisheries in Asia is relatively new. Reservoir fisheries in China is dependent strongly on stocking and recapture whereas, in the rest of Asia, it is dominated by species capable of sustaining or supplementing the stock through natural recruitment. Yields between reservoirs vary greatly and the evidence indicates that yield is not necessarily determined by reservoir morphometry. Possible future developments of reservoir fisheries in the region are highlighted.*

In most of South Asia, reservoirs have been associated with rice cultivation. As such, reservoirs have been important both culturally and socially. The impact of rice cultivation and reservoirs on different cultures varies and is superficially dependent on the terrain, etc. For example, those civilizations that developed on floodplains are not associated with an irrigational tradition. Possibly the greatest cultural impact of reservoirs is evident in Sri Lanka (Fernando and De Silva 1984; De Silva 1983, 1988a). It should also be pointed out that small reservoirs such as the temple ponds have been associated with religion.

In most Asian countries, even though reservoirs are old, the development of reservoir fisheries occurred only relatively recently. This is documented in the cases of Sri Lanka (Fernando and Indrasena 1969; De Silva 1988a) and China (Lu 1986). The potential of the reservoir fishery in Southeast Asia (Fernando 1980), management aspects of lacustrine fisheries in the tropics (Oglesby 1985), and the ecological impact of tropical, man-made lakes (Petr 1978), as well as other aspects, have been dealt with from different viewpoints over the last decade. Apart from what is cited above there has been an increasing emphasis on studies on reservoir fisheries and the biology of constituent species in Southeast Asia over the last decade. This trend is undestandable in view of the near saturation levels reached by Southeast Asian countries in the exploitation of the available coastal resources (Thia-Eng 1986) and the increasing number of reservoirs. The latter can be utilized as an important, major source of animal protein with a minimal capital input when compared with other fisheries sectors. As such, the inland fisheries in the region, of which a major constituent is the reservoir fishery, is becoming increasingly important not only from the point of view of fish production but also from a sociological aspect, as a means of providing employment to a sizeable section of the population (Thai-Eng 1986).

This paper briefly evaluates the present status of the reservoir fishery in relation to the inland fishery of South and East Asia (FAO 1983) as well as mainland China and steps for optimizing yield from the reservoirs are highlighted. In this evaluation, however, intensive aquaculture in reservoirs is not considered.

The Inland Water Resources

The natural lakes in the region are confined mostly to higher latitudes and to the volcanic areas, such as in Indonesia. The approximate surface area of floodplains, a parameter that is difficult to estimate, is not available for most countries in the region (Table 1). The available reservoir resource in the region is approximately 56,630 km^2, which is close to the prediction of Fernando and Furtado (1975) for 1985. In most countries in the region, with the exception of China and Indonesia, reservoirs constitute the larger lacustrine resource. The reservoir resource, however, is very heterogenous within a country and between countries, there being a wide range in age, size, depth, catchment characteristics, and hydrological regimes, all factors that either singly or collectively could influence fish production. Apart from these biological factors, management factors are also bound to influence fish production.

Fisheries scientists have classified reservoirs in certain countries using different criteria (Table 2). It might be desirable to define basic criteria from the point of view of fisheries development for the region with a view to bringing about uniformity and to help recognize and evolve common strategies for an effective and optimal utilization of these resources.

It is also important to point out that none of the classifications thus far adopted, however simple, has taken into consideration any of the basic limnological characteristics of the reservoirs. It may be possible that more biologically meaningful and managerially useful classifications could be evolved based on limnological parameters rather than basic morphological and morphometric parameters. There is increasing evidence that species success is also dependent on the limnology of the reservoirs. For example, bighead carp performs better in oligotrophic reservoirs and silver carp in eutrophic reservoirs in China (Lu 1986).

In South Asia, attempts to use predictive modeling using criteria such as a morphoedaphic index (Ryder 1982) have been few and far between. Such modeling has been extended successfully to African lakes and reservoirs (Henderson and Welcomme 1974). It is also becoming apparent that geographic information system (GIS) and satellite remote sensing are useful tools that could be utilized for planning fisheries and aquaculture development (Kapetsky et al. 1987).

Table 1. Estimated natural lake, reservoir, floodplain, and total inland water resources (*ha*) of South and East Asia including China.

	Natural lakes		Floodplains			Reservoirs			Total
	A	B	A	B	C	A	B	C	B
South Asia									
Bangladesh	-	292988	-	930000	2832792	-	90648	-	1473101
India	-	720000	-	-	-	-	3000000	-	-
Nepal	-	5000	-	-	-	-	1380	-	-
Pakistan	Very few	-	-	-	-	-	15000	-	-
Sri Lanka	None	-	20000	-	-	125000	139214	-	-
East Asia									
Burma	-	33130	50000	-	-	100000	80000	-	-
Indonesia	1000000	1700000	100000	-	-	50000	27000	-	13751000
Laos	-	-	-	-	-	50000	-	-	-
Malaysia	-	-	8000	-	-	20000	-	79738	-
Philippines	-	200000	100000	-	-	-	19000	18770	-
Republic of Korea	-	53000	-	-	-	-	41000	-	-
Republic of Singapore	-	-	-	-	-	-	-	-	-
Thailand	-	300000	-	-	-	1500000	230000	285272	5500000
People's Republic of China	-	7500000	-	-	-	-	-	2000000	16640000

Source: A, Fernando and Furtado (1975); B, FAO (1983); C, Rahman (this volume) for Bangladesh, Guerrero (this volume) for the Philippines, Chookajorn and Bhukaswan (this volume) for Thailand, Li (this volume) for China, and Baluyut (1984) for Malysia.

Table 2. **Some reservoir classifications adopted by reservoir scientists.**

Country or region	Classification: Criteria	Classification: Groups	Source
People's Republic of China	Volume (m^3)	10^7, large; 10^6-10^7, medium; 10^6, small	Li (this volume)
Southeast Asia	Fish yield (kg/ha)	Negligible; low (10-40); high (100-900); very high (ponds, 900)	Fernando and Furtado (1975)
Sri Lanka	Irrigable capacity, location	Large, medium, minor; hill country	Mendis (1977)[a]

[a]Modified by De Silva (1985a)

Undoubtedly, the potential of these tools in the management and effective utilization of the vast reservoir resource in Asia needs to be given priority.

The Inland Fishery

The total inland fishery (inclusive of shellfish) yield in the region amounted to 5.5 x 10^6 t in 1984, and has shown a gradual increase over the last decade. The increase is approximately 60% over the 1975 production level (Fig. 1). The inland production of the region accounts for more than 50% of the world inland production at present and has increased steadily from 50.1% in 1972 to 57.1% in 1984.

The annual reservoir fish production from 1970 to 1973 in the region considered in the paper (excluding China) was estimated at 60,000 t (Fernando and Furtado 1975). They computed an annual average yield of 20 kg/ha. Fernando and Furtado (1975) as well as Petr (1985) also highlighted the large variability in yields between reservoirs. Recently, data from reservoirs are beginning to be published separately from the other inland resources and the status of the reservoir capture fishery is becoming clearer. The reservoir capture fishery is now recorded to yield over 0.5 x 10^6 t (Table 3). It is also interesting to note the wide range of yield, which does not appear always to be related to the size of the reservoir.

In most reservoirs of the region, passive stationary gear is utilized, of which the gill net or a modified form of it is the most popluar. In countries such as Thailand (Chookajorn and Bhukaswan, this volume), the Philippines (Guerrero, this volume), and Sri Lanka, gill nets are used almost exclusively supplemented by hook and line as well as traps. Lu (1986) reports trawl fishing in reservoirs exceeding 1000 ha, on a limited scale, in China.

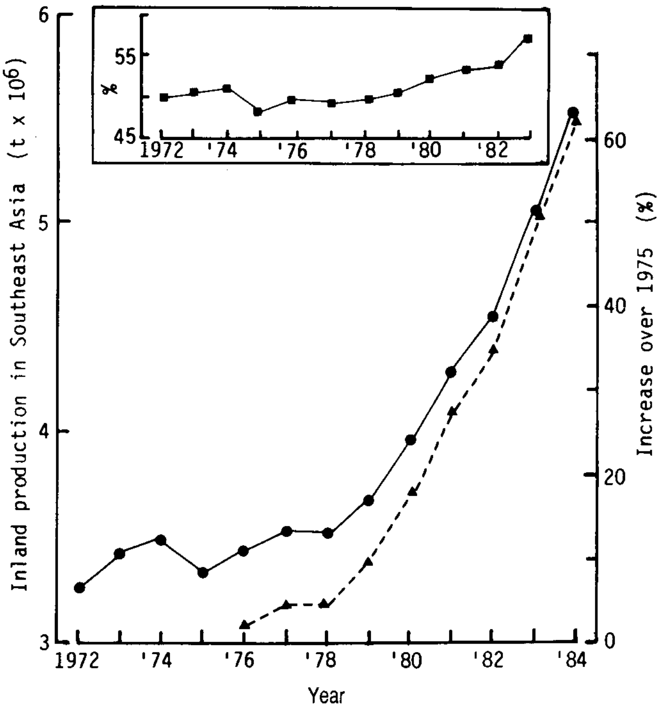

Fig. 1. The inland fish production in Southeast (SE) Asia (including China)(●) and the percent increase in fish production over the 1975 level (▲). The inset shows the percent contribution from the region to the total inland fish production of the world.

Table 3. Fish yields and areas of reservoirs in various Southeast Asian countries.

Country	Yield kg/ha[a]	Yield Total(t)	Area (ha) Min.	Area (ha) Max.	Source
Bangladesh	46	2682	58300		Rahman (this volume)
India	20 (5-100)	200000	-	-	Sharma (1983)
Indonesia	177 (22-353)	4768	8300	22000	Baluyut (1984)
People's Republic of China	150 (75-675)	206434	75	567	Li (this volume)
Sri Lanka	283 (84-650)	27000	650	830	De Silva (1988a)
Thailand	47	13400	1200	41000	Chookajorn and Bhukaswan (this volume)

[a] Mean values with range in parentheses.

The species composition of the reservoir fisheries are also extremely variable between reservoirs within a country and between countries, perhaps with the exception of Sri Lanka (De Silva 1985a). In Sri Lanka, the reservoir fishery is dominated by the exotic cichlid, Oreochromis mossambicus (De Silva 1985a, 1988a). According to Petr (1985), the native cyprinids and 13 other species constituted the bulk of the reservoir fishery catches in Indonesia, the Philippines, and Sri Lanka. Fernando and Furtado (1975) attempted to highlight the importance of exotic cichlids in the reservoir fishery of the Southeast Asian tropics. In China, where the reservoir fishery is strongly influenced by traditional fish culture practices (Lu 1986; Li, this volume), major Chinese carps form the bulk of the catch. Lu (1986) categorically states that, in Chinese reservoirs, the highest yield is achieved by the stocking of species that do not propagate in impoundments and that those species that do propagate contribute only a small proportion to the total yields. In southern Indian reservoirs, the species composition of the catch is variable, the dominance ranging from indigenous species, including the major Indian carps, to the exotic cichlid, O. mossambicus (Sreenivasan 1984).

It is, therefore, correct to conclude that there are no or very few reservoir fisheries in South and East Asia that are dominated by an exotic species, with the exception of the exotic cichlids, O. mossambicus and Oreochromis niloticus. The latter species is knwon to dominate fisheries in Sri Lanka (De Silva 1985a) and in Thailand (Chookajorn and Bhukaswan, this volume).

Management Practices

The paucity of statistical information on the individual reservoir fisheries invariably hinders and limits the adoption of scientific managerial practices, which, in turn, prevents effective optimal utilization of the resources. The management of reservoir fisheries in the tropics is considered to be at an early stage but to be evolving rapidly (Oglesby 1985).

Among the most advocated and widely utilized of management practices is the stocking and recapture technique. The effectiveness of this practice as a tool for increasing the yield in large reservoirs remains controversial. In China, where the fisheries is dependent on stocking, in small- and medium-sized reservoirs (<1000 ha), stocking is considered to be successful when a return of over 10% is obtained (Li, this volume). It is common to get a return of >40% and a stocking efficiency (ratio of yield to stocked biomass) of over 20 (Li 1978). Sreenivasan (1984) evaluated the stocking program in southern Indian reservoirs where the temperatures are suitable for cichlids and concluded that species that contribute less than 10% of the catch or that breed profusely and sustain their own populations should not be considered for stocking. This rules out O. mossambicus and O. niloticus, which are known to be important constituent species of the reservoir fisheries of Sri Lanka, Indonesia, the Philippines, and Bangladesh. Moreover, in the cases cited by Sreenivasan (1984), wherever a transplanted Indian major carp dominates the catch, the overall yield was found to be low (e.g., Rihand Reservoir, 46,583 ha; Nagarjunasagar Reservoir, 28,490 ha). Also, in contrast to the situation in Chinese reservoirs, yields are dominated by species that breed in the impoundments: Catla catla in

Sathanur Reservoir (1,255 ha; mean total annual yield, 126 kg/ha) and catla, rohu, mrigal, and common carp in Govindasagar Reservoir (16,687 ha; annual yield, 28.1-44.0 kg/ha).

The exceptional success of the stocking practices in China is a result of a number of factors. The most important factors being, first, fisheries development is being considered at the construction phase of the reservoir, and second, the stocking size and efficient methods of harvesting made possible by the first factor.

De Silva (1988b) pointed out that it would not be meaningful to stock large, perennial Sri Lankan reservoirs because of the low returns and because profitable, self-sustaining fisheries already exist. One wonders whether it would be profitable to avoid the traditional stocking practices adopted elsewhere and explore other useful means of optimizing the yield from reservoirs, particularly in the tropical part of the Southeast Asian region.

The reservoir fisheries in most countries in the region are not strictly managed scientifically. De Silva (1983, 1985a) pointed out that the imposition of a minimum mesh size regulation in Sri Lanka, determined more by intuition than by scientific reasoning, has indirectly resulted in the conservation of the stocks. Similarly, the uniformity of the gear used in most reservoir fisheries in the region has permitted only a limited exploitation of the resources, both in relation to size and species. More recently, De Silva and Sirisena (1987) have shown the possibility of maintaining two gill net fisheries aimed at exploiting different stocks: the minor, indigenous cyprinid stocks and the exotic cichlid stocks. This is analogous to the exploitation of the introduced freshwater clupeid stocks concurrently with the cichlid stocks in Lake Kariba (Petr and Kapetsky 1983). In brief, research on reservoir fisheries development in the region in the next few years should explore ways and means of effectively utilizing all piscine resources using appropriate technology.

Another important aspect that has seriously hampered scientific management of the stocks in the region has been the lack of suitable predictive models for reservoir fisheries similar to those developed for temperate impoundments (Oglesby 1977; Jenkins 1982; Ryder 1982) and African lakes (Henderson and Welcomme 1974). The lack of such empirical estimates prevents the utilization of effective stocking densities and the imposition of limitations on the fishing efforts in established capture fisheries. In Asia, most reservoirs experience extensive drawdown. Therefore, it may be necessary to look for parameters and indices that are not used in traditional yield-prediction models.

Most reservoirs of Southeast Asia have been constructed for irrigational purposes or to generate hydroelectric power. They are, therefore, subjected to considerable fluctuations in water level. Recently, there has been an increasing amount of evidence on the influence of water levels on fish stock (e.g., Welcomme 1970; Martin et al. 1981; Beam 1983; De Silva 1985b). Hall (1985) pointed out that research on water-level manipulation and its effects on fish populations should be a priority in reservoir fishery management. The importance and the relationship of dam design and operation in optimization of reservoir fish yield has been dealt by Bernecsek

(1984). It is imperative that fisheries scientists convince planners to consider these aspects at the planning stages. Unfortunately, this has not been the case in Asia.

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ABSTRACTS

Present Status of the Reservoir Fisheries in Thailand

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There are presently 20 multipurpose reservoirs in Thailand. Their surface area ranges from 1,200 to 4,100 ha, with a total surface area of 285,272 ha. The physicochemical and biological conditions developed in these impoundments are favourable to fish production. There is, however, a variation in annual fish yield either among reservoirs or within reservoirs caused by several factors including reservoir productivity, number of fishermen, fishing technique, or management measures. It is evident, however, that shallow reservoirs with higher fluctuations in area give better fish yields. The total annual yield in Thailand is estimated at 13,400 t, with an average annual yield of 47 kg/ha. Indigenous species contribute significantly to the harvest, e.g., minnows and clupeids. There are 18,000 fishermen operating in Thai reservoirs. The most popular and effective fishing gear among them is the gill net, and their average daily income is 55 ± 9 THB (in July 1987, 25 Thailand baht [THB] = 1 United States dollar [USD]).

Potential of Reservoir Fishery Development in Nepal

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Nepal is a lanklocked country in which the present per capita consumption of fish is only 391 g/year. There is now 6000 ha of village ponds and 5000 ha of lakes, some of which are dammed. The government of Nepal is embarking on a major reservoir development program that would increase the total reservoir area to 152,220 ha. The fisheries of two existing reservoirs, Kulekhani and Phewa, annually yield 26 and 30 kg/ha, respectively. The observed production of these reservoirs was very close to that predicted by the MEI (morphoedaphic index) model of Henderson and Welcomme developed for African lakes. To augment the natural production from capture fisheries, studies on the introduction of cage culture practices using Chinese and Indian major carps are being conducted. Preliminary results in the Pokhara Valley indicate that 48 t of fish could be produced from 12,000 m^3 of cages. It is suggested that there is a need for further studies on the existing reservoirs and preimpoundment studies on those that are planned.

DISCUSSION

The papers presented in this session outlined the status of reservoir fisheries in the Asian region including Indonesia, Thailand, the Philippines, and Nepal. Five main areas of interest arose in the discussion.

Stocking versus Endemics

Reservoirs in the Asian region are often heavily stocked. In China, small reservoirs are treated in the same way as small ponds. The fisheries rely on stocking and the total cropping, and may be considered as aquaculture. At this point there was much discussion about the definition of aquaculture. To some delegates, reservoirs undergoing continual stocking and removal could be likened to pond culture and considered a form of aquaculture. China wishes to produce large fish for consumption and, therefore, it manipulates the fish population in reservoirs by stocking. In large reservoirs in Thailand, stocking is done more for political reasons than for enhancement and the fishery relies on endemic species. Returns of stocked fish are very low. In general, the cost/benefit ratio of stocking in most Asian reservoirs has not been calculated, but it is considered to be high. This is an area that should be investigated further. In some situations, stocked fish do very well. This is not the case for *Tilapia* sp. in China, where stocking of this species has been unsuccessful.

Turbidity

Increased turbidity usually produces detrimental perturbations to reservoir fisheries. In addition to influencing the feeding and spawning of fish, it can cause the depression of a trophic level. This may be due to reduced light penetration, but, in the case of filter-feeding zooplankton, quantities of mineral particles may be ingested. This could cause these animals to disappear from the system. Thus, increased turbidity often leads to reduced fish production.

Management of Fisheries

In a number of countries, fisherment cooperatives have been formed. This is a relatively new development, however. In most countries, proper management of the high stocks in reservoirs is still in the embryonic stage.

Selective Fishing to Manipulate Species Composition

It was suggested that changes to the fish community be careful, selective fishing may bring about improvement to the fisheries by shifting the utilization of different trophic levels. In the reservoirs small clupeids predominate and, although these are consumed by the countries concerned, others consider them trash fish.

Prediction

Much of the discussion during this session centred on methods of predicting fish yields from reservoirs, in particular from physical and chemical parameters. A number of characteristics need to be taken into consideration, in particular the ratio of catchment to surface area. The morphoedaphic index (MEI) is a baseline predictor of the internal reservoir system and should be related to the nutrient input from the catchment. The yields are probably also related to species composition. Some species utilize one trophic level better than another. This is considered during the stocking of reservoirs in China. The zooplankton to phytoplankton (Z:P) ratio is 1:1 in large reservoirs and 1:4 to 1:5 in small ponds. Thus, bighead carp are stocked in large reservoirs and silver carp are stocked in small ponds. The Z:P ratio is related to fish biomass, however, and should be considered from the top-down approach (the effect of fish grazing) rather than the tradional upward pyramid method. There is general agreement that it is time to work on a new model of predicting fishery yields from Asian reservoirs.

Session II

Limnological Aspects

NUTRIENT CYCLING IN TROPICAL ASIAN RESERVOIRS: SOME IMPORTANT ASPECTS WITH SPECIAL REFERENCE TO PARAKRAMA SAMUDRA, SRI LANKA

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Abstract *General aspects of phosphorus and nitrogen cycling are discussed in this paper. In the temperate region, lakes are found mostly to be phosphorus limited. Based on information derived from primary production and some nutrient-enrichment experiments for a few African lakes, it was postulated that tropical lakes are nitrogen limited. Experiments conducted with radiophosphate in some African lakes, however, provided strong evidence for the existence of P-limited lakes. Investigations carried out in Parakrama Sumudra, Sri Lanka, a reservoir with very low soluble reactive phosphate (SRP) level (average, 9-12 µg/L) indicated the existence of a diel phosphate cycle. The phosphate deficiency indicators measured included alkaline phosphatase activity (PA) and changes in the algal internal P-pool measured as labile phosphate (LP). Because of the enhanced phosphatase activity during the period of maximum production (1200-1500), a depletion of the soluble phosphate level was observed with a parallel increase in the SRP concentration. There appears to be an inverse relationship between the above P-deficiency indicators and the phosphate level in lake water during the day. Experiments carried out with radioactive tracers showed fast turnover rates from 1 to 3 min. Gel filtration analyses of labeled soluble phosphate (SP) indicated the presence of a larger fraction of high molecular weight P bound as colloidal P during midday, which is not readily available. All this evidence show clearly a P-deficient situation in the lake, which can limit primary production. In comparison with overlying water, the sediment nutrient content is higher by two orders of magnitude and mineralization processes seem to play an important role. Because of the resuspension of sediments, a larger proportion of the benthic mineralization is shifted to the pelagic zone. Combined pelagic and sediment-water interface mineralization serve as important mechanisms for the replenishment of the dissolved nutrient pool.*

The biological processes occurring in a water body are greatly influenced by the chemical environment. Some of these processes involve energy interconversion, ultimately leading to the production of organic compounds; nutrients play a key role in regulating the rate and pattern of this energy flow through the aquatic ecosystem. Primary production links carbon assimilation and element incorporation into the tissue; it is influenced by both biotic and abiotic factors. At the organism level, the energy to drive nutrient cycles is derived from carbon, which also provides the skeleton to store other elements.

In aquatic ecosystems, plant growth relies on the availability of some 20 nutrient elements, of which the majority are required to trace amounts (Reynolds 1984). The movement of these elements and inorganic components from one compartment (pool) to another in the system is referred to as nutrient cycling. Nutrient dynamics determine the fundamental environmental conditions governing the primary and, thus, the overall biological production. Oxygen, carbon, nitrogen, and phosphorus are required in large amounts; P and N are considered to be the most essential nutrients for plant growth. The short supply of any one of these nutrients leads to limited growth (Likens 1972). In most aquatic systems in the temperate region, the limiting nutrient is phosphorus (Vollenweider 1968; Fricker 1980); to a smaller degree, nitrogen is also limited (Golterman 1975).

A great deal of work has been done on temperate lakes and reservoirs but such investigations are lacking for the tropics. The work done on nutrient cycles during the International Biological Programme (IBP) in Africa (Viner 1973, 1975; Peters and MacIntyre 1976) clearly emphasized the features that make tropical aquatic ecosystems different from temperate aquatic ecosystems. So far, little attention has been paid to detailed investigations on nutrient cycling in tropical Asian reservoirs (Gunatilaka 1980). There is some sparse information available on nutrient cycling in Laguna de Bay, a shallow brackish water lake in the Philippines (Barica 1976; Bautista 1983), Sankey tank in South India, and Nakhaurpatna pond in North India (Ayyappan et al. 1986). Gunatilaka (1983, 1984) and Gunatilaka and Senaratna (1981) discuss in detail the nutrient dynamics in Parakrama Samudra, an ancient man-made reservoir in Sri Lanka, during the dry and wet seasons. As there is detailed limnological information available on this reservoir (Schiemer 1983), it is used as a model study here to discuss nutrient cycling in reservoirs in the tropical Asian region.

Nutrient Cycling

Golterman (1975) summarized the phosphorus and nitrogen cycles in lakes schematically by phosphorus and nitrogen flow diagrams (Figs. 1 and 2). In Fig. 1, the recycling of phosphorus through the biological compartments and the sediments are shown with arrows indicating the direction of flow. Phosphorus is supplied by the surrounding inputs and parent geological material. Exchange of phosphorus between the dissolved and particulate compartments is a dynamic process and the supply and rate of cycling of P controls the size of the biological and organic components. If phosphate is present above growth-limiting levels, it may lead to luxury uptake in algae (Kuenzler 1970) and be stored as polyphosphates. The ratios between cellular carbon and phosphorus are more or less constant and according to Redfield et al. (1963). For marine algae this ratio is around 106:1; for most IBP lakes, 50:100; for phosphate-limited phytoplankton, around 60:1 (Golterman 1975). During primary production, if the phosphate supplies are low, mineralization has to occur either in the water column or at the bottom (Fig. 1) to supplement the demand. The phosphate recycling in the water column (central part of the Fig. 1) is referred to as an "internal" or "metabolic" P cycle. The phosphate recycling through the sediments is known as a "geochemical" or "external" P cycle and various aspects of it are dealt with in Golterman (1977).

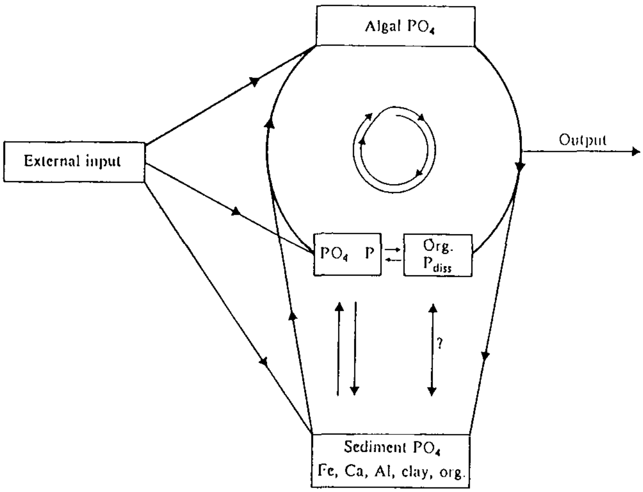

Fig. 1. Phosphate flow diagram visualizing the recycling of phosphate through the biological compartments (adapted from Golterman 1975).

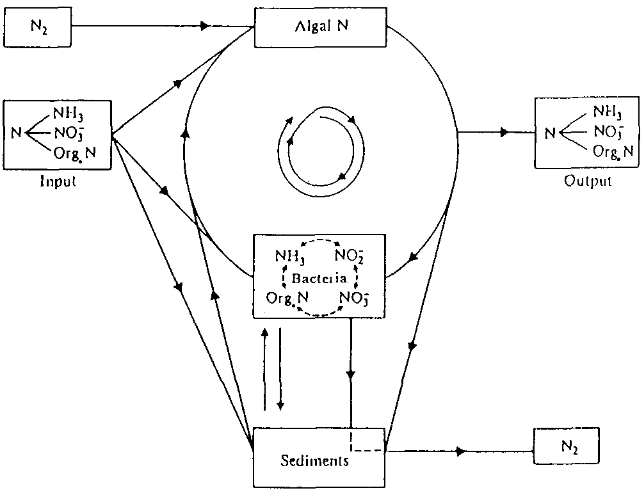

Fig. 2. Schematic represenation of the nitrogen cycle (adapted from Golterman 1975).

For nitrogen, the primary source is the atmosphere (Fig. 2). The nutrient cycling, whose source of energy is carbon, is controlled by phosphorus. The main differences between the nitrogen and phosphorus cycles are twofold. First, nitrogen may enter and leave the cycle as gaseous nitrogen through fixation and denitrification, respectively (which make nitrogen budget calculations more complicated). Second, amino acids provide an important part of the energy available to bacteria and to zooplankton that assimilate algae.

Inorganic sources of N for algae are ammonia, nitrates, and gaseous nitrogen in cases where N fixation occurs. Cyanobacterial nitrogen fixation is generally accepted as one of the major factors controlling primary production in N-limited environments. The fixed nitrogen in aquatic environments is readily oxidized and reduced by biologically catalyzed reactions. The uptake of inorganic nitrogen is dependent on carbon sources, either from active photosynthesis or from heterotrophic growth from carbon accumulated during photosynthesis under N deficiency. The algal nitrogen content will be up to 10% of the dry weight and, after the death of algae, a rapid mineralization will occur, mostly by bacterial action. By this process, nitrogen is liberated mainly as ammonia with some organic nitrogen compounds. The phytoplankton preference of ammonia as a nitrogen source is well documented (Reynolds 1984) and Viner (1973) reports that in Lake George (Uganda) ammonia compounds were used by algae rather than nitrate.

Talling and Talling (1965), based on their observations of East African lakes, suggested nitrogen could be a limiting factor in tropical waters. Subsequently, P- and N-enrichment experiments carried out with natural plankton in Lake Chilwa (Moss 1969) and Lake George (Viner 1973) showed that nitrogen produced a greater stimulus to algal production than did phosphorus. Similar experiments in reservoirs in Brazil, the vareza Lago Jacartinga (Zaret et al. 1981), Lake Titicaca (Wurtsbaugh et al. 1985), and turbid waters of the Amazon River (Grobbelaar 1983) demonstrated the relative importance of nitrogen. However, rapid rates of radiophosphate turnover have been recorded (Peters and MacIntyre 1976) for some East African lakes (Table 1). A similar situation is reported for Parakrama Samudra, Sri Lanka (Gunatilaka 1983; Gunatilaka 1984), indicating a phosphorus limitation. Nutrient enrichment experiments in Lake McIlwaine, Lake Kariba, and three other man-made reservoirs in Zimbabwe, phosphorus appeared to show a great stimulus (Robert and Southall 1977).

Nutrient Cycling in Parakrama Samudra

Parakrama Samudra, in Sri Lanka, is one of the larger reservoirs (22 km^2) of an ancient (386 A.D.) irrigation system. The reservoir is located in the north central provide (7°55' N, 81° E, 58 m above sea level) at Polonnaruwa within the dry zone; the seasonal hydrological regime reflects the monsoonal cycle and the irrigation demands for rice cultivation in the district. A comprehensive account of the limnology of the lake is given in Schiemer (1983).

According to the lake classification scheme of Vollenweider (1968), Parakrama Samudra could be described as a highly eutrophic lake. The nutrient loading of the lake is mainly a result of comparatively high nutrient content of the inflow, runoff from the catchment area (especially during monsoonal periods), cattle droppings and human wastes in dry falling zones of the lake, the impact of birds (especially cormorants), and dry precipitation. The dissolved nutrient concentrations measured in lake water, however, are relatively low (0-6 µg/L premonsoon; 3-6 µg/L postmonsoon). As SRP concentration is relatively low, the high primary production rates recorded for the lake (Dokulil et al. 1983) are indicative of an efficient P-recycling mechanism.

Diurnal measurements of phosphate deficiency indicators such as inducement of phosphatase activity (PA), changes in the algal internal

Table 1. Rate constants for orthophosphate incorporation (k) and PO_4^{3-} turnover times (tt) in Parakrama Samudra, Sri Lanka, and some Sri Lankan lakes.

Date (day-month-year)	Lake[a]	Time (h)	k (min^{-1})	SRP (µg/L)	tt (min)
	Sri Lanka[b]				
27-7-1982	PSN	1300	0.713	4	1.41
30-7-1982	PSN	1300	0.788	5	1.27
31-7-1982	PSN	1300	0.780	4	1.31
10-8-1982	PSM	1300	0.761	6	1.31
12-8-1982	PSN	0700	0.330	9	3.02
	Kenya[c]				
28-6-1974	Elementeita		1.50	<3	0.66
26-6-1974	Naivasha, main basin		1.00	<3	1
27-6-1974	Naivasga Crater		0.20	<3	5
24-6-1974	Nakuru		0.0029	23	345
25-6-1974	Nakuru		0.0014		714
30-6-1974	Nakuru		0.0010		1000
17-7-1974	Nakuru		0.0039	7	256
26-6-1974	Crescent Island Crater		0.0000	117	

[a]PSN, Parakrama Samudra north; PSM, Parakrama Samudra middle.
[b]Gunatilaka (1984).
[c]Peters and MacIntyre (1976).

P pool measured as labile phosphate (LP), as well as soluble reactive phosphate (SRP), soluble phosphate (SP), soluble unreactive phosphate (SUP), and particulate phosphate (PP), have shown the existence of a diel phosphate cycle (Table 2). The higher phytoplankton and bacterial biomass (Table 2) and production during the period of maximum light intensity would have contributed to the distinct diel patterns of SRP, SP, SUP, LP, and PA in the water column. The diel changes in these parameters indicate the varying external conditions as well as the physiological conditions of the phytoplankton and microbial populations. The slow disappearance of SP during the period of highest production may be due to the high SRP demand. This is evident from the increase of PA in the water column. It is probable that some of the SUP is hydrolyzed as a result of the increased enzymatic activity, which is reflected by the drop in the SP level. The ability of the phytoplankton to hydrolyze dissolved organic phosphate compounds and inorganic polyphosphates is well documented. The slight drop in LP at midday corresponds to the depletion of the internal algal P pool at the time of maximum production. In Parakrama Samudra, there appears to be an inverse relationship between external inorganic phosphate concentration and both phosphorous deficiency parameters: the labile P (LP) and phosphatase activity.

Radiophosphate uptake experiments with lake water showed fast turnover rates (Table 1, Fig. 3) and the large rate constants demonstrate dynamic exchnage between particulate phosphate and soluble reactive phosphate (SRP). A turnover time of around 1 min measured during the peak production period clearly indicates that the algal and bacterial populations are P deficient. Gel filtration analysis of

Table 2. Diel changes in soluble reactive phosphate (SRP), soluble phosphate (SP), particulate phosphate (PP), labile phosphate (LP, measured as hot water extractable P), total and dissolved phosphatase activity (PA-T and PA-D, respectively), and total bacterial counts (TB) at station 14, Parakrama Samudra north, 6 August 1982.

Time (h)	Depth (m)	SRP (µg/L)	SP (µg/L)	PP (µg/L)	LP (µg/L)	PA-T[a]	PA-D[a]	TB[b]
0630	0.5	4	28	49	11	0.55	0.14	13
	1.0	4	22	39	9	0.73	0.03	16
	1.5	3	34	57	9	0.79	0.07	18
	2.3	4	34	58	10	0.74	0.13	25
0930	0.5	6	26	54	13	0.12	0.12	34
	1.0	5	29	64	11	0.07	0.07	18
	1.5	3	31	70	8	0.08	0.08	29
	2.3	5	28	50	8	0.14	0.14	32
1230	0.5	12	22	59	6	0.64	0.64	44
	1.0	2	23	66	4	0.15	0.15	38
	1.5	2	23	66	4	0.12	0.12	54
	2.3	6	28	51	8	0.10	0.10	18
1530	0.5	8	18	46	4	0.13	0.13	46
	1.0	8	16	76	4	0.11	0.11	59
	1.5	5	16	56	5	0.13	0.13	63
	2.3	9	10	46	4	0.13	0.13	36
1830	0.5	8	24	62	8	0.09	0.09	40
	1.0	4	32	59	8	0.15	0.15	38
	1.5	9	34	64	11	0.07	0.07	44
	2.3	6	33	37	9	0.07	0.07	34

(continued)

Table 2. Concluded.

Time (h)	Depth (m)	SRP (µg/L)	SP (µg/L)	PP (µg/L)	LP (µg/L)	PA-T[a]	PA-D[a]	TB[b]
2400	0.5	9	24	44	7	0.08	0.08	26
	1.0	26	32	71	9	0.07	0.07	33
	1.5	24	36	74	10	0.07	0.07	17
	2.3	17	32	53	9	0.07	0.07	9
0600	0.5	4	32	47	8	0.12	0.12	22
	1.0	8	38	56	10	0.07	0.07	22
	1.5	4	34	63	13	0.11	0.11	17
	2.3	8	34	58	11	0.08	0.08	12

[a]Alkaline phosphatase activity: micromoles PNPP hydrolyzed per hour per milligram protein (lake samples).
[b]Total bacteria x 10^5 per millilitre.

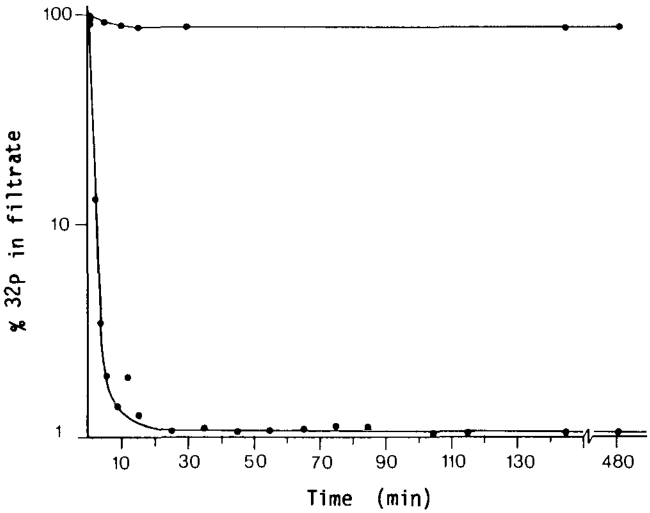

Fig. 3. $^{32}PO_4$ uptake kinetics in Parakrama Samudra showing the percentage $^{32}PO_4$ remaining in solution after addition to an integrated lake water sample from 0 to 1.5 m depth (station 14, Parakrama Samudra north). Distilled water was used as the control.

labeled soluble P suggested that a large fraction (ca. 70%) of it is high molecular weight P (Fig. 4). This shows that much of the dissolved P in the lake water is colloidally bound and, therefore, not readily available to the plankton. In lakes with high colloidal levels, phosphate movements may differ from the scheme proposed by Lean (1973a,b).

In Lake George, Viner (1975) pointed out the importance of resuspended sediments for nutrient cycling. According to the investigations of Bauer (1983), in Parakrama Samudra, convective currents produced by thermal events appear to play an important role. Strong water currents will erode the uppermost layers of sediments and, as a result, a part of the benthic mineralization is shifted into the pelagic zone (Newrkla 1983). In Parakrama Samudra, the ratio of pelagic to benthic mineralization is 9:1. The oxygen supply to the sediments stimulates the benthic community metabolism, leading to increased metabolic rates, which imply faster decompositon of organic matter and recyling of much-demanded nutrients for primary production. Thus, 90% of the primary production is compensated for by pelagic decomposition processes; the remaining 10% is respired at the sediment surface (Newrkla 1983).

According to Hargrave (1973), benthic oxygen consumption is quantitatively related to the flux of oxidizable organic matter to the sediment and he derived an expression to calculate the photsynthetically fixed carbon respired at the sediment surface. The mineralization rates calculated using this relationship are given in Table 3. The contribution from the mineralization indicates the importance of nutrient flux from sediments in Parakrama Samudra to a nutrient-poor water column. This is in contrast to the findings of Viner (1977) in Lake George.

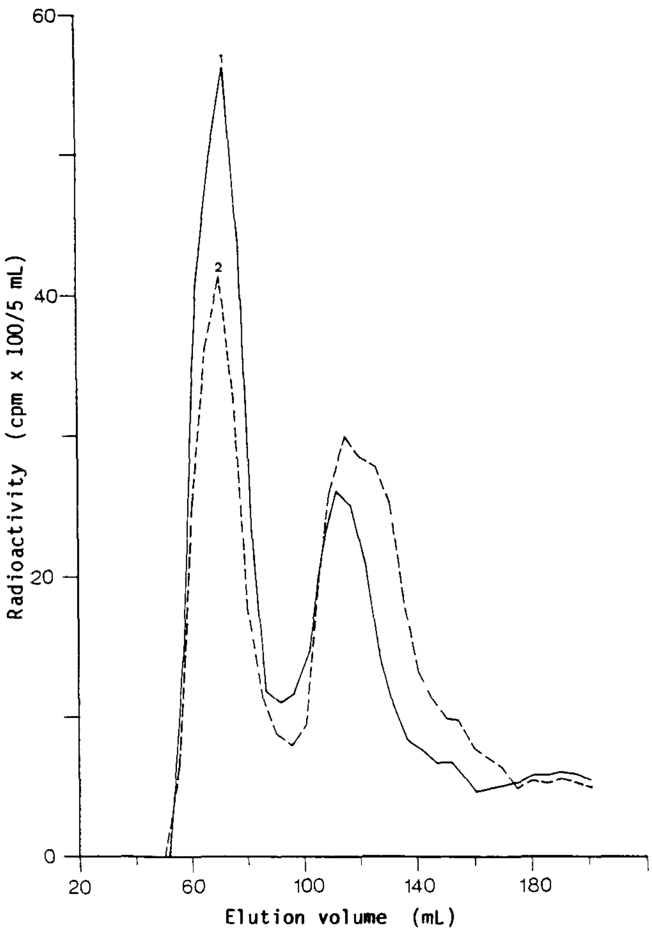

Fig. 4. Sephadex gel (G 25) filtration of filtrates after 30 min equilibration with $^{32}PO_4$. The peak (colloidal P) occurs from 51 to approx. 91 mL (void volume; MW, 5000). Curves 1 and 2 are from integrated lake water samples from 0 to 1.5 m at station 14, Parakrama Samudra north, collected at midday and morning, respectively.

Conclusions

The following features of Parkrama Samudra ecosystem bear direct relationship to nutrient cycling: comparatively low nutrient concentration in lake water; high algal biomass; and high sediment nutrient content. Because the dissolved nutrient concentrations are low, dependence on internal recycling of nutrients. According to Viner (1973) in Lake George, the primary production keeps pace with combined mineralization an influent rates; a similar situation is encountered in Parakrama Samudra.

In comparison to overlying water, the sediment nutrient content is higher by two orders of magnitude. This implies that large amounts of nutrients are buried in the sediments. The total phosphorus (TP)

Table 3. Predicted sediment-water nutrient flux in Parakrama Samudra calculated by coupling to primary production and in site benthic respiration measurements.

Location	Respiration rate (mg/m^2 per h)[b]	Mineralization of carbon in sediment (mg C/m^2 per h)	Rate of release of ammonia from sediment (mg NH_4/m^2 per h)	Rate of release of phosphate from sediment (mg PO_4/m^2 per h)
PSN, station 1	24.55-35.93	3.12-3.23	0.25-0.29	0.016-0.018
PSN, station 8	31.76-36.87	2.86-3.32	0.24-0.27	0.015-0.017
Middle of lake	46.79-51.05	4.21-6.84	0.33-0.53	0.021-0.033
Average values				
PSN	34.92	3.14	0.26	0.016
PSM	69.30	4.42	0.34	0.021
PSS	68.00	4.34	0.35	0.022

[a]PSN, PSM, and PSS: Parakrama Samudra north, middle, and south, respectively.
[b]Newrkla (1983).

content is aroung 1:5 mg/g dry weight. Organic phosphate accounts for 1/5 of the TP and the concentration drops with depth (at 15 cm, a reduction of 45-50%). This indicates that the organic phosphate is actively mineralized to supplement the depleted dissolved P pool. The alkaline phosphatase activity measured was three times higher than in water but decreased with depth (parallel to the drop in P concentration). All these observations show that mineralization processes are playing an important role in the flux of phosphorus from the sediments. The total nitrogen content of the surface sediments is 16-18 mg/g and a decrease of 29-36% was observed with depth. Although there are slight fluctuations in N:P, C:P, and C:N ratios, they lie within the values described in the literature from eutrophic lakes. The high algal biomass seems to contribute toward the autochthonous sedimentation and is evident from the high N:P ratios and C values recorded for sediments in the upper 5 cm, (N:P ratio approaches 15:1, which is similar to that of algae).

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EFFICIENCY OF TWO TYPES OF NETS FOR SAMPLING MICROCRUSTACEAN ZOOPLANKTON IN THREE SRI LANKAN RESERVOIRS AND A DISCUSSION OF SAMPLING METHODS

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Abstract *The efficiency of different methods for collecting microcrustacean zooplankton is evaluated in three Sri Lankan reservoirs of different productivity. The catches of two plankton nets (80 and 335-µm mesh) are compared with the catches of the Ruttner bottle, a 2-L volume sampler. Productivity has a pronounced negative effect on the efficiency of the 80-µm mesh hauls. Vertical hauls are always more effective than horizontal hauls, although only ca 50% of the organisms present in the water column of the reservoir are collected. The 80-µm mesh net has a low catching efficiency because of clogging. In the 335-µm mesh net, a high proportion of the smaller organisms are lost through the mesh. It is concluded that, for monitoring studies, vertical net hauls can be used after calibration; however, for population dynamics and production studies, a volume sampler should be used. Sampling strategies and samplers to be used in monitoring or population dynamics and production studies are discussed in detail.*

As part of a pilot program for the project on the population dynamics and production of microcrutacean zooplankton (Vijverberg et al., this volume) several different sampling methods were carried out simultaneously to collect zooplankton in three Sri Lankan reservoirs during December 1985. This additional sampling program had three main objectives: firstly, for calibrating the routinely used horizontal net (335-µm mesh) hauls; secondly for comparing the efficiency of the horizontal net haul with that of the vertical net haul; and, finally, for comparing the efficiencies of the fine-mesh net (80 µm) hauls and the coarse-mesh net (335 µm) hauls.

Materials and Methods

Two types of nets and one volume sampler were used simultaneously for sampling in three reservoirs in Sri Lanka. One net was a simple 85-µm mesh net (mouth diameter, 25 cm; height 49 cm); the second net was an Apstein-type, 335-µm mesh plankton net of 130 cm length, with a cone on the mouth (upper diameter, 16.5 cm) to increase efficiency. With the two nets, both horizontal and vertical hauls were made. For the horizontal hauls, the net was hauled horizontally at a depth of ca 1 m for 20 s behind a boat traveling at a speed of ca 1 m/s. Vertical net hauls were made from the bottom toward the surface, and the depth of the water column was measured for each haul.

Volume samples were taken with a 2-L Perspex Ruttner bottle (column height, 22 cm; diameter, 11 cm) at the same site where the vertical and horizontal net hauls were taken. Ten samples (total, 20 L) were collected at each depth. In the deepest reservoir (Muruthawela), samples were collected at five depths: just below the surface, 2, 5, 10, and 15 m, which was just above the bottom. In the shallow reservoirs (Tissawewa and Yodawewa), samples were colleced at three depths: just below the surface, just above the bottom, and at an intermediate depth. Samples from the same strata were pooled and concentrated by filtration through an 80-µm mesh plankton gauze. One of the pooled samples from Yodawewa was split in two fractions: water was first sieved through an 80-µm mesh filter and then through a 30-µm mesh filter. Most samples were subsampled before counting with a broad-mouth pipette. A minimum of 200 individuals from each sample were counted. For more information on the methods, see Vijverberg et al. (this volume).

The three reservoirs have different dimensions (Table 1). Tissawewa is the most eutrophic in terms of chlorophyll-a concentration, followed by Yodawewa, which is also eutrophic, and Muruthawela, which is mesotrophic (Table 1). For more information about the study area see De Silva and Sirisena (1988).

Results and Discussion

Efficiency of 80-µm Sieve for Retaining Nauplii

The two fractions of the Yodawewa sample were compared. This sample was split into an 80-µm fraction, which was collected with an 80-µm sieve, and a 30-µm fraction, which was collected with a 30-µm sieve after passing through an 80-µm sieve. Nauplii were observed in the 30-µm fraction only. By comparing the total number of nauplii in this fraction with the total number of nauplii in the 80-µm fraction, the efficiency of the 80-µm sieve for retaining nauplii can be calculated. The 80-µm sieve recovers 97% of the nauplii. Thus, this mesh is sufficiently fine for the quantitative collection of nauplii.

Efficiency of the Horizontal (335-µm Mesh) Net Haul

The efficiency of the horizontal (335-µm mesh) net hauls is low and roughly similar in the two reservoirs (Table 2). The mean

Table 1. Dimensions and mean chlorophyll a content of three Sri Lankan reservoirs.

Reservoir	Surface area (ha)	Maximum depth (m)	Chlorophyll a content (mg/L)
Muruthawela	516	36	8
Tissawewa	234	5	31
Yodawewa	488	4	14

efficiencies for all the taxa are 15% for Muruthawela and 10% for Yodawewa. There are significant differences in efficiency between taxa. Larger species such as Diaphanosoma spp., Moina micrura, and calanoid copepods have relatively large efficiencies; small species such as Ceriodaphnia cornuta and the cyclopoid copepods show low efficiencies of around 1%. This is obviously because of the coarse mesh used; however, the vertical zooplankton distribution, with relatively low densities in the surface layers, may also play a role (see Vijverberg et al., this volume).

Comparison of Efficiencies

The 335-µm net is usually less efficient for small species (e.g., Ceriodaphnia cornuta and cyclopoid copepods), but is relatively efficient for large calanoid copepods. Vertical hauls are generally much more efficient than horizontal hauls (Table 2). The largest differences in efficiency are observed when we compare the 80-µm mesh horizontal haul in eutrophic Yodawewa (mean efficiency, 1%) with the 80-µm mesh net vertical haul in the same reservoir (mean efficiency, 68%). Conversely, the 80-µm mesh net horizontal haul in the mesotrophc Murathawela is much more efficient (mean efficiency, 37%). This difference is likely due to the severe clogging of the 80-µm net during the horizontal haul in Yodawewa; this occurred to a much lesser degree in Muruthawela because of the much lower seston concentration. More clogging is to be expected in the horizontal haul in Yodawewa because, during this haul, the net is towed over a distance that is 13 times longer than that of the vertical haul.

Effects of Mesh Size on Efficiency

Generally, only minor differences are found between the efficiencies of the vertical 335-µm mesh net haul and the vertical 80-µm mesh net haul in the same reservoir. The relatively large

Table 2. Net efficiency[a] of vertical and horizontal hauls of 335- and 80-µm mesh net for various taxa of microcrustacean zooplankton.

	Vertical haul					Horizontal haul				
	335-µm mesh			80-µm mesh		335-µm mesh		80-µm mesh		
Taxon[b]	M[c]	Y	T	M	Y	M	Y	M	Y	T
Calanoids	94	79	47	35	7	48	14	33	1	8
Diaphanosoma	70	30	33	54	13	8	27	16	1	2
Moina	91	5	29	64	2	14	8	29	1	6
Ceriodaphnia	45	7	42	95	6	1	1	78	1	5
Cyclopoids	5	1	19	49	4	2	1	33	1	8

[a]Net efficiency is expressed as the proportion (percent) of individuals caught per litre of water as compared with the Ruttner volume sampler.

[b]Taxa are listed in order of decreasing size.

[c]M, Muruthawela; Y, Yodawewa; T, Tissawewa.

difference in Yodawewa is possibly due to the relatively high density of small cyclopoid copepods. The range of mean efficiencies is usually 30-70%. The catching efficiency of the 80-µm mesh net is lowered by the effects of clogging, and, in the 335-µm mesh net, a high proportion of the smaller species are lost through the larger openings. When comparing horizontal hauls, the effects of reservoir productivity on net efficiency are evident. In the less productive Muruthawela, the 80-µm mesh net is more efficient. Conversely, the 335-µm mesh net is more efficient in the productive Yodawewa.

Conclusions

Horizontal (80- and 335-µm mesh) net hauls are inefficient for collecting microcrustacean zooplankton and, hence, it is advised that this method not be used for estimating zooplankton densities. Both the 80- and 335-µm mesh vertical net hauls are usually more efficient; however, these methods still miss 50% of the population. In spite of this, after calibration, vertical net hauls are probably good enough for monitoring microcrustacean zooplankton populations. For population dynamics and production studies, however, a volume sampler is recommended.

Discussion of Sampling Methods

Introduction

This discussion is limited to two types of studies: those with the object of monitoring the microcrustacean zooplankton community as a whole and those detailed studies on the production or dynamics of selected microcrustacean zooplankton species populations. Monitoring the whole community can be useful when checking the stability of the zooplankton community or when following the annual or seasonal changes in the densities of the main taxa. Clearly, less accuracy is desired for monitoring than for population studies. For monitoring studies, the same type of sampling gear must be used at all times, samples can be taken at random or at fixed sampling sites, and samples must be collected at regular intervals. In most cases, a 1-month interval between collections is appropriate.

Published information on zooplankton production in the tropics is meagre (Dumont and Tundisi 1984; Dussart et al. 1984). The available information comes mainly from Lake Chad in Africa (e.g., Gras and Saint-Jean 1983), Lake George in Africa (Burgis 1974), and Lake Lanao in the Philippines (Lewis 1979). During the recent congress on tropical zooplankton in Sao Carlos, Brazil, more work on the secondary production of zooplankton in tropical water using a population-dynamics approach was strongly recommended (Dumont and Tundisi 1984). In this approach, besides the population density and population structure, it is necessary to measure the duration of egg and instar stages in relation to temperature and to assess instar body weights.

Sampling Strategies

Sampling accuracy is not only related to the type of sampling equipment used but is also largely affected by sampling design (for a review, see Prepas 1984). Zooplankton are usually not uniformally distributed, either horizontally or vertically. Their distribution tends to be patchy, often with a strong vertical gradient of abundance that changes continuously over 24 h (diel vertical migration). Because of this contagious distribution, several samples should be taken to estimate the mean population density of zooplankton.

The number of samples to be collected at each sampling date should be carefully considered. Too few samples will render the sampling useless; too many samples will result in a precision higher than that desired and, consequently, will cost more labour and money. The method of calculating the approximate numbers of samples depends on the distribution pattern of the population to be studied. Often the zooplankton distribution is not approximately normal but approximates either a Poisson or a contagious distribution. For all those instances where the exact distribution is not known, Elliott (1977) proposed a method for estimating the number of samples required:

$$N = \frac{S^2}{(D^2)(\bar{x}^2)}$$

where N is the required number of samples, S^2 is the variance (SD is standard deviation and $S_{\bar{x}}$ is standard error [$S_{\bar{x}} = SD/\sqrt{N}$]), $\bar{x}$ is the mean population density, and D is the allowable size of the ratio of the standard error to the mean ($S_{\bar{x}}/\bar{x}$). Depending on the degree of clumping of the zooplankton populations present, the absolute population densities, and the number of samples taken at each sampling date, an accuracy of 50-85% is usually possible. In a relatively large (21 km^2), well-mixed, temperate reservoir (Tjeukemeer, Netherlands), an accuracy greater than 80% can be reached. (Percent error is expressed as the coefficient of variation ($SD/\bar{x} \times 100$) for $\bar{x} > 10$ individuals/L when 20 samples are collected at 10 systematically distributed sampling stations (Nie et al. 1980; Nie and Vijverberg 1985)).

Prepas (1984) recognizes four main sampling designs: random, stratified, systematic, and composite. With random sampling, random sites are located at each sampling date. A random number table is often used. Occasionally, the environment to be sampled has many fairly homogeneous patches, but there may be large differences between individual patches. Under these circumstances, stratified random sampling can add considerable precision to the population estimate with a minimum of additional effort. Stratified sampling is also necessary for production and population-dynamics studies when different thermal strata are present.

Systematic samples are evenly spaced throughout a designated area, with the initial sampling point chosen randomly. Systematic sampling is more even than random sampling and easier to set up. It is often used for plankton samples when individual samples are pooled. Although information on spatial variation is lost in composite samples, pooling of samples is often necessary when it is infeasible to analyze individual samples. In routine sampling programs, composite sampling is often combined with random, stratified, or systematic sampling. During the 1st year of research, composite sampling should be avoided so that spatial variation can be studied. In following years, samples should be pooled into one or a few composite samples (stratified sampling); this saves much time in analyzing (Nie et al. 1980; Vijverberg and Richter 1982).

Effects of Mesh Size on Filtering Capacity

Tropical microcrustacean zooplankton vary in size from 80 to 2000 µm, including different taxa and instar stages. The ability to escape collection varies among taxa and depends on the size, stage, shape, and behaviour of the organism. The smallest organisms (nauplii and early instar copepodites) may be filtered quantitatively with an 80-µm sieve; for larger organisms (e.g., cladocerans and advanced copepodite instars), a 120-µm mesh is usually more appropriate; a 250- to 350-µm mesh is usually appropriate for most adult copepods and cladocerans.

The smaller the mesh, the higher the proportion of small individuals retained on the net, but the sooner the net will clog. Thus, for small species present in high densities, small volumes of water should be filtered over fine-mesh gauze. For larger species present at low densities, large volumes of water should be filtered over coarse-mesh gauze.

With a net of a given mesh size, as towing speed increases, filtering capacity decreases (for a review, see Tonolli 1971). If the aperture size of the net is decreased from 363 to 76 µm, clogging and pressure within the net become severe. With the coarse net (363-µm mesh), the upper critical towing speed, where errors in metering the flow effect the estimated density from the catch, is around 1.0 m/s. With a 76-µm mesh net in unproductive waters, the maximum towing speed is about 0.8 m/s; this drops around 0.5 m/s in productive waters. In productive waters, both the speed and the length of the tow must be reduced.

When fine nets are absolutely necessary, the only alternative is to increase the effective filtering area of the net (i.e., increase the ratio of the area of the mouth of the net to the filtering surface from the normal 1:7 to 1:15 or greater). In most cases, however, and especially in productive waters, nets finer than 363-µm mesh should not be used (Tonolli 1971).

Subsampling Device

Because of the financial constraints of a research project, it is generally impossible to count an entire plankton sample. The distribution of microcrustacean individuals in a sample is often random, but counts of several subsamples should be performed to check whether the variance to mean ratio indicates random distribution. The estimate of the mean is usually accurate when each subsample contains 50-150 individuals (Prepas 1984).

Many devices have been used to subsample zooplankton samples before counting: the modified Folsom splitter (Longhurst and Seibert 1967), the whirling vessel of Kott (1953), and the George splitter (George et al. 1984) are the most accurate (for a review, see Van Guelpen et al. 1982). The modified Folsom and George splitters divide a sample into 2 equal parts; the subsampler of Kott divides a sample into 10 equal parts.

Sampling Gear

Sampling gear for freshwater zooplankton has been reviewed by Bernardi (1984). Five types of equipment are used in freshwater studies: water bottle, trap-type volume sampler, tube sampler, towed plankton samplers (e.g., Clarke-Bumpus), and simple plankton nets. The first three types are all volume samplers. Because water bottles, although similar in many other aspects, show a lower catching efficiency than trap-type volume samplers, they are not discussed here. Even if a flowmeter is used inside the net, net catches should regularly be calibrated against a trap-type volume sampler. This calibration should be repeated several times a year because the seston concentration in the water will substantially affect efficiency.

Trap-Type Volume Samplers

Trap-type volume samplers are generally considered to be the most efficient zooplankton samplers currently available (Schindler 1969; Redfield 1984; Ni and Vijverberg 1985). They are especially recommended for production and population-dynamics studies (Bernardi 1984).

Tube Samplers

Tube samplers are useful in shallow reservoirs and littoral zones with macrophyte vegetation. The length of the tube corresponds to the maximum depth to be sampled. Two types are commonly used: a flexible tube and a stiff, Perspex tube. For long cores (>3 m), a rubber or plastic tube with thin, flexible walls is used. One of the most advanced tube samplers was developed by George and Owen (1978). This flexible tube sampler (diameter, 10 cm) provides a quick and efficient way of collecting zooplankton to a depth of around 10 m. According to George and Owen (1978), the efficiency of this tube sampler to that of most trap-type volume samplers. For short cores (<3 m), a Perspex tube can be used (Nie et al. 1980).

Towed Plankton Samplers

Several high-speed towed samplers have been designed, but most of these can only be operated from large boats. The Clarke-Bumpus (Bernardi 1984) is the only towed sampler that has been regularly used for sampling freshwater zooplankton. This sampler can be operated from a small boat and samples can be collected along vertical, horizontal, or sinusoidal hauls within a selected layer of water. The Clarke-Bumpus is essentially a plankton net fixed to a frame and connected to a flowmeter. The netting should have a mesh size greater than 80 µm; in productive reservoirs a mesh size of 150-200 µm is usually used (Duncan and Gulati 1981; Newrkla and Duncan 1984). The effiency of the sampler has been tested against trap-type volume samplers. Schindler (1969) reports an efficiency of around 60% as compared with the Schindler trap; most other authors report higher efficiencies (e.g., Bernardi 1984).

The Clarke-Bumpus should be calibrated. When calibrated in a laboratory flume, where all the water from a metered source passes through the Clarke-Bumpus, the sampler accepts a relatively constant volume. The calibration for an individual sampler may vary from 4 to 5 L per revolution of the flowmeter between towing speeds of 0.25 and

Table 3. Recommendations for the choice of sampler to be used in assessment of microcrustacean zooplankton densities.

	Study purpose		Reservoir conditions					
Sampler type	**Monitoring**	**PPDS[a]**	**Deep**	**Shallow**	**Littoral**	**Very productive**	**Productive**	**Unproductive**
Trap-type volume sampler	+	++	-	++	-	++	+	-
Tube sampler	++	++	-	++	++	++	+	-
Clarke-Bumpus	++	+	++	+	-	+/-	+	++
Simple net	++	-	+	-	-	-	-	+

Note: ++, good; +, appropriate; -, poor.
Source: Bernardi (1984).
[a]Production and population-dynamics studies.

0.90 m/s. Below 40 revolutions/min, friction in the metering assembly makes the capacity appear higher; above 140 revolutions/min, back pressure reduces capacity. Each sampler should be initially calibrated in the laboratory and periodically checked in the field, where the sampler can be towed between fixed buoys separated by a known distance (Tonolli 1971).

Simple Nets

Nets are still the most common gear in the tropics for sampling zooplankton. If possible, a water flowmeter should be attached to the net. Nets may be practical when large quantities of water are to be filtered, i.e., in deep reservoirs (vertical hauls) or in lakes with low zooplankton densities. Shape and structure greatly affect the quantity of water that can pass through the mouth of a net (Unesco 1968). Plankton nets with a reducing cone placed forward of the mouth, such as the Hensen and Apstein nets, and with a filtration area at least three times larger than the area of the mouth are most efficient.

Recommendations

The choice of sampler depends on the purpose of the research and the conditions of the reservoir (Table 3). Generally, trap-type volume samplers are best for production and population-dynamics studies, and tube samplers, the Clarke-Bumpus sampler, or nets are preferred for monitoring studies. However, much depends on the local conditions of the reservoir. In deep, pelagic, unproductive waters, the Clarke-Bumpus sampler is preferred; simple nets are also appropriate. In contrast, in shallow, eutrophic reservoirs, trap-type volume samplers are best. Tube samplers are the only type that can be used efficiently in the littoral zone with macrophyte vegetation.

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SEASONAL DYNAMICS OF COPEPODS AND CLADOCERANS IN FIVE SRI LANKAN RESERVOIRS

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Abstract *The seasonal density variations of cladocerans and copepods in five Sri Lankan reservoirs were studied from June 1985 to December 1986. The vertical distribution of the major taxa has been investigated in three of the reservoirs. In all five reservoirs, 23 species were recorded. The most common species include 7 cladocerans, 2 calanoid copepods, and 4 cyclopoid copepods. All the species are not present in all the reservoirs; the number of common species observed per reservoir is 10-12. This is a greater species diversity than that in most temperate lakes in Europe and North America.*

Among aquatic animals, microcrustaceans such as copepods and cladocerans play an important role in the productivity of most aquatic systems. The efficiency of energy transformation between the autotrophic and the first heterotrophic level in the aquatic food web depends on the productivity of these animals (Sushchenya 1970).

In temperate and northern regions, obligate zooplanktivorous fish, predominantly 1st-year class (0+) fish, predate heavily on planktonic microcrustaceans (e.g., Densen 1985). These 0+ fish are generally all particulate feeders and manifest a clear size selectiveness in their predation, preferring the large individuals of large zooplankton species.

Microcrustaceans are less important in Southeast Asian tropical reservoirs because most of the fish inhabiting these reservoirs feed on algae or detritus, and, in some cases, are supplemented with macrofaunal elements such as chironomid larvae and gastropods (Fernando 1956; Hofer and Schiemer 1983; Schiemer and Hofer 1983). Nevertheless, this generalization is mainly based on analyzing the gut contents of adult fish; small juvenile fish, however, have rarely been studied. Thus, the importance of zooplankton as fish food in Southeast Asian reservoirs may have been underestimated. Duncan (1983) observed substantial densities of microcrustacean zooplankton in a littoral region of Parakrama Samudra North (Sri Lanka) between macrophyte vegetation; microcrustaceans were present in very low densities (<0.001 individuals/L) in the open-water zone of this reservoir (Duncan and Gulati 1981). In contrast with the fish caught in the open-water zone, fish from the littoral zone appeared to contain microcrustacean remains in their guts. Small juvenile tilapia (Oreochromis mossambicus; total length (TL), 10 mm) and a small freshwater clupeoid (Ehirava fluviatilis; TL, 25 mm) were found to feed on chydorid cladocerans (mainly benthic) and the planktonic calanoid copepod, Phyllodiaptomus. As E. fluviatilis was the most abundant fish in the open-water region of this reservoir, Duncan (1983) hypothesized that the young, small fish were effectively eliminating the planktonic microcrustaceans in the open-water area.

Maitipe and De Silva (1985) analyzed the diets of adult Oreochromis mossambicus in 12 Sri Lankan reservoirs. Of the populations studied, 4 fed partially on microcrustacean zooplankton and 1 was predominantly zooplanktivorous. Thus, under specific environmental conditions, even the adults of O. mossambicus, generally considered to be an algae-detritus feeder, are zooplanktivorous.

The zooplanktivorous half-beak (Hyporhampus gaimardi) is sometimes abundant in Sri Lankan reservoirs. This species, which is predominantly estuarine and coastal, occasionally migrates in large numbers to freshwater reservoirs.

An increased importance of microcrustacean zooplankton as a fish food may have interesting implications. In this situation, many fish will consume zooplankton and compete with zooplankton for algal and sestonic food (Nilssen 1984). The heavy size-selective predation may have resulted in the scarcity of large cladoceran species, notably the large, efficient, filter-feeding Daphnia spp. (Fernando 1980a,b).

To improve our understanding of the role of zooplankton in the food webs of tropical reservoirs, population dynamics and production must be studied (Dumont and Tundisi 1984). Published information on zooplankton of tropical reservoirs and lakes, however, is meagre (Dussart et al. 1984). The available information is mainly from one lake (Lake Chad, Chad, Africa) (e.g., see Gras and Saint-Jean 1983). For this reason, our objective is to study the population dynamics and production of a number of dominant microcrustacean zooplankton species in a few Sri Lankan reservoirs of different trophic status. The data represented here on the seasonal dynamics and vertical variation of zooplankton densities are the preliminary results of a pilot study carried out from June 1985 to December 1986. Net efficiency results are presented in a separate paper (Vijverberg, this volume).

Study Area

Five man-made lakes in southeastern Sri Lanka were studied (surface area, maximum depth): Badagiriya (482 ha, 4.3 m), Muruthawela (516 ha, 36.0 m), Ridiyagama (888 ha, 5.3 m), Tissawewa (234 ha, 5.0 m), and Yodawewa (488 ha, 4.0 m). Other studies are also being carried out in these reservoirs (De Silva and Sirisena 1987; Sirisena and De Silva 1988). These reservoirs represent a wide range of characteristics and are thought to be representative of Sri Lankan reservoirs (De Silva and Sirisena 1987). Badagiriya, Tissawewa, and Yodawewa are ancient reservoirs built between the 1st and 6th century A.D. and generally restored during the first part of this century. Ridiyagama (1923-1928) and Muruthawela (1968) were built recently. In terms of chlorophyll content (De Silva and Sirisena 1987), Badagiriya is the most productive, followed by Tissawewa; Yodawewa and

Ridiyagama, though eutrophic, are less productive. Muruthawela is the least productive and may be classified as mesotrophic. For more details on these reservoirs, see De Silva and Sirisena (1987).

Methods

Routine sampling was carried out with an Apstein-type, 335-µm mesh plankton net. The mouth of the net was equipped with a 130 cm long cone with a 16.5 cm upper diameter. The samples were usually collected at one site at monthly or bimonthly intervals during the day. The net was hauled horizontally for 20 s at a depth of 1 m behind a boat travelling approximately 1 m/s.

In December 1985, an additional sampling was carried out in Muruthawela, Tissawewa, and Yodawewa to calibrate the efficiency of the 355-µm mesh standard net haul. Volume samples were taken with a 2-L Perspex Ruttner bottle at the same site as the standard horizontal net haul. Only one site was sampled in each reservoir; 10 samples (20 L) were collected at each depth. In the deepest reservoir, Muruthawela, five depths were sampled: just below the surface, and at 2, 5, 10, and 15 m (just above the bottom). In the shallow reservoirs, Tissawewa and Yodawewa, only three strata were sampled: just below the surface, just above the bottom, and an intermediate depth. Samples from the same strata were pooled and concentrated by filtration through an 80-µm mesh plankton gauze. All samples were preserved in 4% formalin. Most samples were subsampled before counting, using a broad-mouthed pipette. A minimum of 200 individuals were counted in each sample. Cyclopoid and calanoid copepods were classified using the keys of Dussart and Fernando (1985); cladocerans were classified using the descriptions of Fernando (1974, 1980a) and Rajapaksa and Fernando (1982).

The calculated net efficiencies for each taxa were used to estimate the absolute population densities from the net catches. Since Yodawewa and Ridiyagama are more or less equally productive and Tissawewa is similar to Badagiriya (De Silva and Sirisena 1987), the net efficiencies of Yodawewa and Tissawewa were used for Ridiyagama and Badagiriya, respectively. Net efficiency results are presented in a separate paper (Vijverberg, this volume).

Results

Vertical Distribution

The youngest instar stages of both calanoid and cyclopoid copepods, the nauplii, were grouped together. Highest densities were generally recorded at intermediate depths; at the surface and bottom layers, densities appear to be much lower (Fig. 1).

Seasonal Density Variation

Seasonal density variation is wide both between and within reservoirs (Fig. 2). The highest zooplankton densities were observed in the highly eutrophic Tissawewa. The mesotrophic Muruthawela, however, showed the second highest densities. The three other reservoirs showed similar but somewhat lower densities. Comparing the

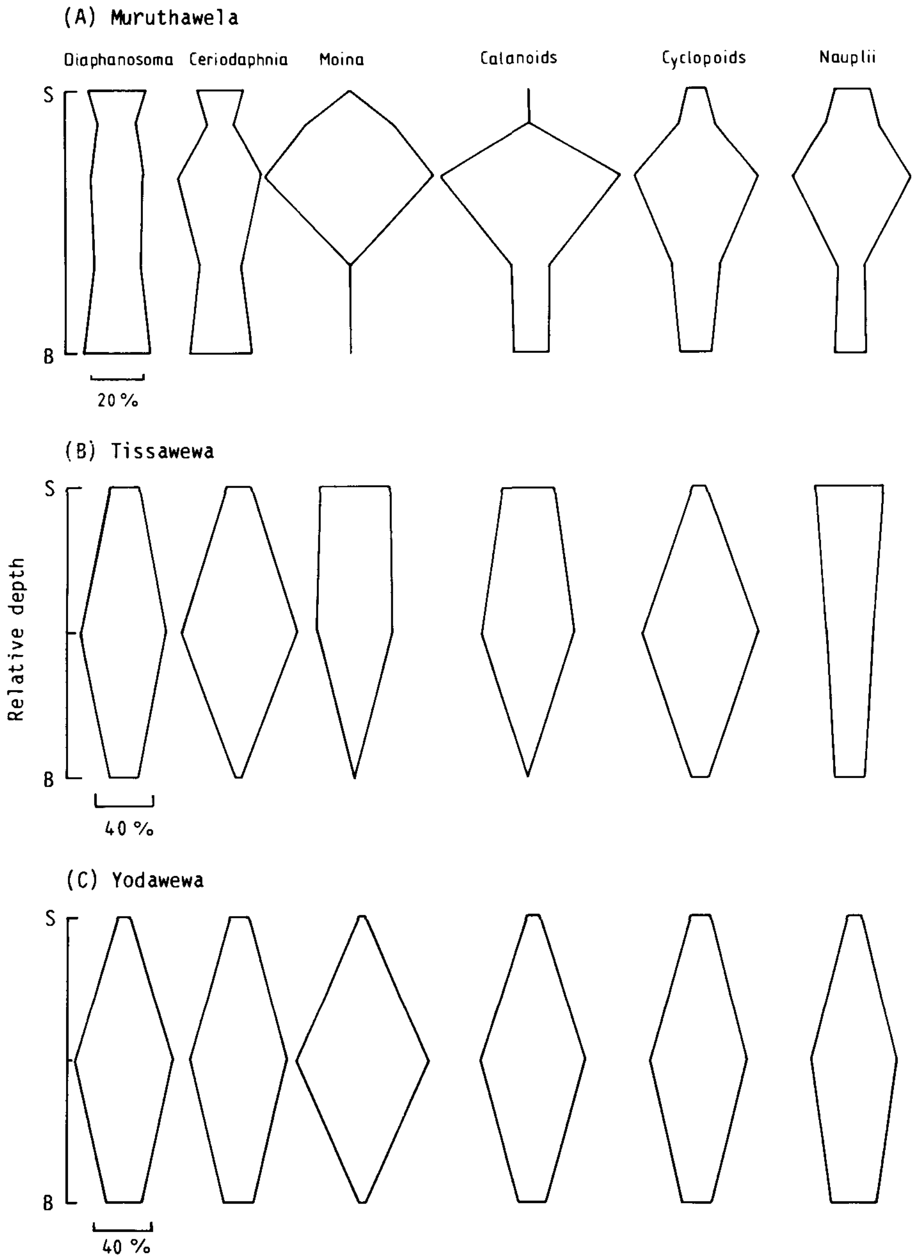

Fig. 1. Vertical distribution of microcrustacean zooplankton in three Sri Lankan reservoirs (October 1985): S, surface; B, bottom.

densities of the main taxa, differences were observed between reservoirs. Tissawewa showed the highest densities of cladocerans and calanoid copepods and Muruthawela exhibited the highest densities of cyclopoid copepods.

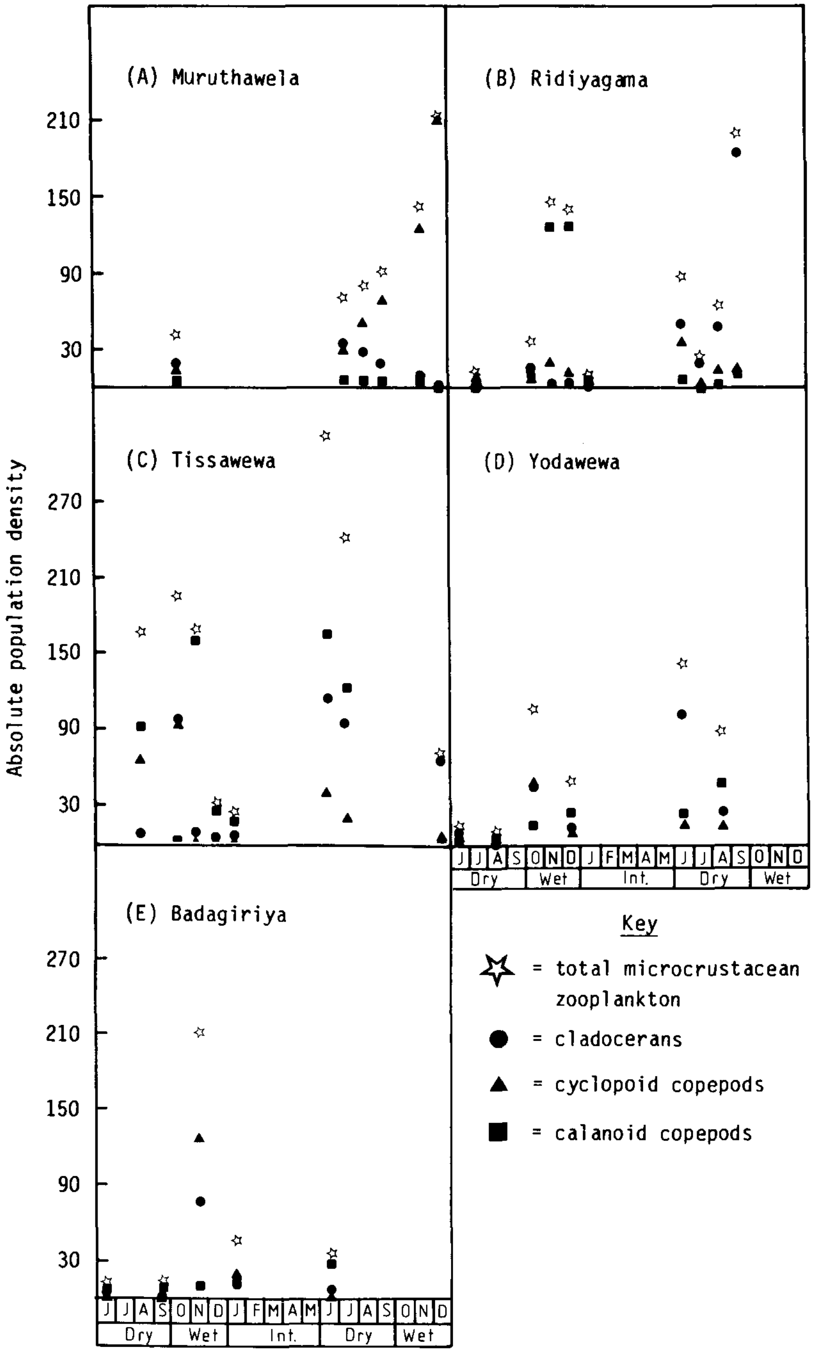

Fig. 2. Seasonal (wet, dry, intermediate) variation in absolute population densities (individuals per litre) of microcrustacean zooplankton in five Sri Lankan reservoirs.

There are marked temporal changes in the densities. As no samples were taken during the "intermediate" season (January-May), the seasonal impact on density is difficult to interpret. Thus, only preliminary conclusions can be made. Cyclopoid copepods are most abundant in the wet season (June-September) and cladocerans are most abundant in the dry season (October-December). Calonoid copepods showed density maxima in both seasons.

A total of 23 microcrustacean zooplankton species were recorded: 12 cladoceran species, 5 calanoid copepod species, and 6 cyclopoid copepod species (Table 1). Of these, 11 species were comparatively rare. Other species (Diaphanosoma sarsi, Daphnia lumholtzi, Bosminopsis dietersi, Thermocyclops cf. decipiens, and Thermocyclops orientalis) were not present in all reservoirs. The numerically most abundant species were Diaphanosoma modigliani, Ceriodaphnia cornuta, Moina micrura, Heliodiaptomus viduus, Mesocyclops splendides, and Mesocyclops cf. thermocyclopoides.

Discussion

Most of the common species observed here are eurytopic and are also common in other Sri Lankan reservoirs (Apstein 1907; Fernando 1980a; Fernando and Rajapaksa 1983; Jayatunga 1982) and in reservoirs throughout Southeast Asia (Fernando 1980b). There are a few exceptions, however. In this study, D. modigliani was recorded relatively in higher densities than Diaphanosoma excisum. Fernando (1980a) regarded D. modigliani as rather rare in Sri Lanka and Jayatunga (1982) did not observe it in Kalawewa Reservoir. On the contrary, we observed this species in all five reservoirs. With regard to calanoid copepods, Phyllodiaptomus annae exhibits much lower densities than H. viduus. Fernando (1980a), however, considered P. annae the only common calanoid copepod in Sri Lanka. This view is also supported by the observations of Apstein (1907, 1910) in Beira Lake and Gregory Lake and of Fernando and Rajapaksa (1983) in Parakrama Samudra. Jayatunga (1982), however, reported two dominant calanoid species for Kalawewa: P. annae and H. viduus. Moreover, the cladoceran species Chydorus barriosi was not observed or, when present, was encountered in only very low densities. It is listed, however, as a common species in reservoirs of Southeast Asia (Fernando 1980b) and was regularly observed in Parakrama Samudra between 1957 and 1980 (Fernando and Rejapaksa 1983).

The species diversity of limnetic copepods and cladocerans seems to decrease progressively towards the equator, contrary to what is commonly considered to be the case in other animal groups (Dumont and Tundisi 1984). This is corroborated by Fernando (1980a), who showed that the numbers of species occurring in the temperate regions of Great Britain and Ontario (Canada) were approximately 50% higher than in tropical Sri Lanka. The species diversities in the above-mentioned studies are being measured as "occurrence" in a large geographical area without taking into account the abundance of the particular species. Thus, the species diversity according to Fernando (1980a) also includes rare species, which are not important in the food web. If the present results, based on the number of common species present per lake are compared with those of the temperate and northern lakes, we get a totally different picture. We observed 13 common species in

Table 1. **Mean population densities (individuals per litre) of microcrustacean zooplankton species in five Sri Lankan reservoirs during 1985 and 1986.**

Species	Muruthawela (6)[a]	Yodawewa (6)	Tissawewa (8)	Ridiyagama (9)	Badagiriya (5)
Cladocera					
Sididae					
Diaphanosoma excisum Sars	2.7	1.0	7.7	2.1	2.0
Diaphanosoma modigliani Richard	0.5	20.8	4.0	5.0	2.3
Diaphanosoma sarsi Richard	-[b]	-	3.4	6.2	0.1
Daphniidae					
Ceriodaphnia cornuta Sars	10.3	4.0	19.5	21.8	14.6
Daphnia lumholtzi Sars	-	-	2.4	-	+[b]
Molinidae					
Moina micrura Kurz	2.8	7.8	12.6	1.1	1.1
Bosminidae					
Bosminopsis dietersi Richard	1.6	-	-	-	-
Macrothricidae					
Iliocryptus spinifer Herrick	-	+	-	-	-
Macrothrix spinosa King	-	-	+	+	-
Chydoridae					
Chydorus sphaericus (Müller)	+	+	+	+	-
Chydorus barriosi Richard	+	+	0.1	+	-
Leydigia acanthocercoides (Fisher)	-	-	-	+	-
Pleuroxus sp.	-	-	0.2	-	-

(continued)

Table 1. Concluded.

Species	Muruthawela (6)[a]	Yodawewa (6)	Tissawewa (8)	Ridiyagama (9)	Badagiriya (5)
Copepoda					
Calanoida					
Allodiaptomus cinctus (Gurney)	0.1	0.2	-	0.2	-
Heliodiaptomus viduus (Gurney)	2.2	17.7	71.4	28.4	14.0
Neodiaptomus handeli (Brehm)	0.1	0.5	-	0.8	-
Neodiaptomus strigilipes (Gurney)	-	0.1	-	+	-
Phyllodiaptomus annae (Apstein)	0.9	1.7	3.0	1.6	0.3
Tropodiaptomus orientalis (Brady)	0.1	-	-	0.4	-
Cyclopoida					
Mesocyclops splendidus	7.6	13.3	8.3	7.6	10.6
Mesocyclops cf. *thermocyclopoides* (Harada)	65.8	1.4	12.9	3.6	10.9
Microcylops varicans (Sars)	+	-	-	-	-
Thermocyclops cf. *decipiens* Kiefer	0.9	+	2.2	-	-
Thermocyclops orientalis Dussart & Fernando	8.8	+	5.9	-	6.7

[a]The number of sampling dates is shown in parentheses.
[b]-, not observed; +, rare.

the reservoirs (7 cladocerans, 2 calanoids, and 4 cyclopoids). The number of common species observed per reservoir was 10-12. Morgan et al. (1980) reviewed the zooplankton composition of around 70 water bodies from temperate and northern Europe and temperate North and South America. The lakes of northern Europe showed the highest species diversity with 6-15 common species of copepods and cladocerans; however, most temperate European lakes showed a lower number of common species. In the North and South American temperate lakes, the species diversity (5-9 common species) was markedly lower. Thus, if species diversity is based on both occurrence and abundance, the species diversity of Sri Lankan reservoirs is high, similar to that of northern European lakes and higher than that of most temperate European and temperate South and North American lakes.

A certain degree of seasonality is noted in the variation of densities of some of the main taxa. These changes may be related to the rainfall, but more and better data are necessary for firm conclusions. Regular, weekly or biweekly, sampling should be carried out over long periods. Moreover, the heavy rainfall during the wet season may positively or negatively affect zooplankton population densities depending on the local situation (Hart 1985). Dilution in endorheic basins or increased wash out in exorheic systems can decrease zooplankton densities directly or indirectly through decreasing food resources. Conversely, nitrogen-rich rainfall or runoff carrying nutrients and allochthonous organisms serve to increase the resources for the zooplankton, either directly or after a lag period. Besides rainfall, wind may also serve as a determinant of seasonality (Hart 1985).

Surprisingly, little is known about the absolute population densities of copepods and cladocerans in Sri Lanka. There are only three studies available, two by Duncan and Gulati (1981) and by Fernando and Rajapaksa (1983) on the microcrustacean zooplankton densities of Parakrama Samudra (1978-80) and the other by Jayatunga (1982) on the densities of copepod and cladoceran species in the Kalawewa Reservoir. The densities reported from Parakrama Samudra are 10-250,000 times lower than the densities observed in this study. This may be due to the heavy fish predation on the zooplankton in Parakrama Samudra (Duncan 1983). The densities reported for Kalawewa are similar to our observations.

The absolute population densities of copepods and cladocerans observed in the five reservoirs in the course of this study are high enough to expect them to play a substantial role in the food web. More elaborate investigations are necessary to elucidate the exact importance of these communities.

Acknowledgments

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ENERGY FLOW AND PRESENT STATUS OF SMALL IRRIGATION RESERVOIRS IN SOUTHERN TAMIL NADU, INDIA

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Abstract *Southern Tamil Nadu is "the land of irrigation tanks," which are seasonal and highly productive, and in which heterotrophic succession lasts longer than autotrophic succession. The mean daily productivity of the ponds in which macrophytes are the major producers ranges from 8.2 to 12.0 mg C/m^2. In a typical pond, this translates into an annual productivity of 600 t C, of which 264 t (44%) is lost because of plant respiration. The photosynthetic efficiency of these ponds is 1.3% and the net primary production efficiency is 56%.*

To control flooding and increase the area of irrigated agricultural land, 1554 large reservoirs were constructed by the Government of India from 1951 to 1980 (Agarwal et al. 1982). Besides these new reservoirs, there are thousands of small, ancient irrigation tanks. For example, there are 7,457 (48,060 ha) and 5,016 irrigation tanks in the Madurai and Ramnad revenue districts, respectively; hence, this area is aptly described as "the land of irrigation tanks." About 6% (439) of the tanks in the Madurai District hold water for more than 9 months/year (permanent); about 15% (1145) hold water for around 6 months/year (semipermanent); the remaining 79% (5873) hold water for about 3 months/year (transient) (Table 1). The district receives 120 cm of precipitation annually, of which 72 cm (60%) is experienced in the northeast during the monsoon period from September-October to December-January. Many of the irrigation tanks in southern Tamil Nadu are fed by the Vaigai River. The tanks situated at the head of the river are more permanent than those situated at the end of the river.

Productivity and Succession

In some of the permanent tanks, biological productivity is dominated by macrophytes; in others, phytoplankton dominate. The reasons for this difference in dominance are not yet known; in fact, a study on the dynamics of primary productivity in these ponds has yet to be initiated. Although a large number of these tanks are semipermanent or transient, most are characterized by a high annual productivity (25,000 kcal/m^2). Immediately following the monsoon season, large populations of copepods and daphnids emerge from diapause long before algae begin to appear (e.g., Sumitra 1971). Utilizing the rich organic debris, planktonic organisms and insects

Table 1. Classes of irrigation tanks in the Madurai District of Tamil Nadu, India.

Taluk	Permanent No.	Permanent Area (ha)	Semipermanent No.	Semipermanent Area (ha)	Transient No.	Transient Area (ha)
Periyakulam	38	689	52	791	363	557
Uthamapalayam	22	425	48	548	157	399
Nilakottai	42	1275	77	1151	454	753
Usilampatti	1	1699	72	2045	569	1130
Madurai South	14	220	88	2296	250	529
Madurai North	180	3348	14	274	165	460
Melur	119	1307	252	1655	1947	5902
Tirumangalam	-	-	160	5792	826	1491
Kodaikanal	1	41	-	-	13	2
Palar	21	665	27	699	117	4996
Dindigul	1	1	232	2089	714	1998
Vedasandur	-	-	123	1535	298	1298
Total	439	9670	1145	18875	5873	19515

dominate the pond longer than the primary producers do (Sumitra 1971). Heterotrophic succession lasts longer than autotrophic succession in transient ponds.

In ecosystems with macrophytes as the major producers, the daily gross primary productivity (GPP) ranges from 8.2 to 12.0 mg C/m^2. In ecosystems with phytoplankton as the major producer, daily GPP ranges from 0.5 to 5.0 mg C/m^2. The daily GPP in some phytoplankton ponds in Tamil Nadu may reach 15.9 mg C/m^2 (Table 2). The reasons for the higher GPP values in the macrophyte ponds are not clear and merit detailed investigation.

Most irrigation tanks, however transient, are used as "service centres" for irrigation and for many domestic reasons including drinking. Because of silting, eutrophication, and urbanization, however, many of these irrigation tanks are changing. The situation in southern Tamil Nadu calls for detailed limnological studies to improve productivity, promote heterotrophic succession, and improve rural hygiene.

Morphometry and Productive Belt

Phytoplanktonic productivities of some major and minor reservoirs in Tamil Nadu have been previously reported (Sreenivasan 1963, 1964, 1967, 1969). A typical irrigation tank from Palni, southern Tamil Nadu, is subjected to wide and frequent changes in morphometry owing to heavy precipitation from October to December and rapid evaporation from April to July. Accordingly, the ponds reach their maximum holding capacity by November every year (Table 3). Because of irrigation and other domestic functions, the water mass decreases to about 50% by March. Because of evaporation, the area covered by water

Table 2. Daily gross primary productivity (GPP) and net primary productivity (NPP) of various ecosystems.

Ecosystem	Major producer	GPP ($mg\ C/m^2$)	NPP ($mg\ C/m^2$)	Source
Pond Idumban	Macrophytes	8.2	4.6	Haniffa and Pandian (1978)
Kavaratti Atoll	Macrophytes	12.0	5.8	Qasim and Bhattathiri (1971)
Turtle grass flat	Macrophytes	10.6	3.1	Odum (1956)
Norwegian lake	Phytoplankton	0.5	-	Lande (1973)
Madurai ponds	Phytoplankton	5.0	3.0	Sumitra (1971)
	Phytoplankton	3.1	1.9	
	Phytoplankton	2.0	0.9	
North Indian pond	Phytoplankton	3.2	1.7	Nasar and Datta -Munshi (1975)
Tamil Nadu ponds	Phytoplankton	0.7-15.9	-	Sreenivasan (1967)

reaches a minimum of 6% in August. Because the typical irrigation tank contains murky water, the productive littoral area changes rapidly and considerably: 24% of the total tank area in October-January to a minimum of 2% in September. Therefore, to understand the dynamics of productivity and succession in irrigation tanks, GPP must be considered with respect to the unit weight of the producers, the unit area of the tank, and the entire tank as a unit.

Productivity and Energy Flow

The major producers in the irrigation tanks are Chara fragilis, Hydrilla verticillata, and Ceratophyllum demersum, which flourish for 8-10 months beginning in October and exhibit a typical exponential, J-shaped population growth curve. The standing biomass steadily increases from 18 g/m^2 in September to a maximum of 631 g/m^2 in April (Table 3). The GPP increases from 4 mg/g per day in September to a maximum of about 112 mg/g per day in November (Table 3). The subsequent decrease is perhaps due to the build-up of standing biomass and the consequent competition for light and nutrients. The trend obtained for GPP per unit area, however, was slightly different, increasing from 0.5 g/m^2 per day in September to 14 g/m^2 in May. The GPP per unit area reaches a maximum when the standing biomass peaks (Table 3). When the tank is considered as a unit, November to April is the most productive period. The total annual productivity of the tank is 585 t. The annual amount of solar energy that enters the pond is 1,956,000 $kcal/m^2$. Of this, 24,682 $kcal/m^2$ is fixed by the macrophytes, i.e., the photosynthetic efficiency is 1.3% and the net primary production efficiency is 56%.

Table 3. Monthly variation in the area covered by water, the productive littoral area, the standing biomass, and the gross primary productivity (GPP) of macrophytes in the littoral areas of a typical irrigation tank in southern Tamil Nadu.

Month	Area covered by water (%)	Productive littoral area (%)	Standing biomass (g dry weight/m^2)	GPP: mg dry substance produced/g plant per day	GPP: g dry weight/m^2 per day	GPP: t/pond per month
September	6	2	18	4	0.5	8
October	93	22	53	106	3.0	28
November	100	23	126	112	6.0	60
December	100	24	163	108	7.0	74
January	97	21	184	97	7.0	70
February	71	18	300	88	8.0	70
March	49	15	475	76	12.0	88
April	34	12	631	63	12.0	74
May	25	9	581	51	14.0	57
June	17	7	366	27	4.0	32
July	8	6	283	14	3.0	19
August	6	5	86	9	0.8	5

Source: Haniffa and Pandian (1978, 1980).
Note: Values are the means of two irrigation tanks in Palni, southern Tamil Nadu, India.

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WATER-QUALITY CRITERIA FOR THE PROTECTION OF AQUATIC LIFE AND ITS USERS IN TROPICAL ASIAN RESERVOIRS

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Abstract *This paper presents a preliminary attempt to establish water-quality criteria for the protection of aquatic life and its users in tropical Asian reservoirs. Some 40 organic chemicals, predominantly pesticides and herbicides, that are commonly found in tropical Asian reservoirs and associated waterways and accumulate in the tropical biota, have been chosen for the derivation exercise. The available pertinent data that permit a rational and quantitative derivation exercise are reviewed. Some incomplete data sets are also included to identify priority research areas. A two-number criterion is developed in terms of criterion maximum concentration level and criterion 24-h average concentration. This two-number criterion recognizes that aquatic organisms can tolerate short exposures to concentrations of pollutants higher than those they can tolerate continuously.*

The increasing usage and variety of organic chemicals in tropical Asian agrobased countries is placing a heavy pollution burden on the aquatic environment. The extensive use of pesticides and herbicides has created concerns over their effects on living aquatic resources in Thailand: i.e., freshwater fish epidemic of 1983 (Menasavet et al. 1983), acute toxicity of paraquat in many Thai freshwater fish (such as Cypripus carpio and Ophicephalus striatus), and histopathological effects in the gills of Thai silver barb (Puntius gonionotus) (Sinhaseni and Tesprateep 1987). In Malaysia, pesticides and herbicides may be responsible for some cases of fish mortality attributed to unknown causes (Kanniah 1983). Water-quality management is, therefore, of fundamental importance to the preservation of aquatic ecosystems.

The formulation of water-quality criteria is a cost-effective management tool and is necessary in maintaining balanced aquatic ecosystems in tropical Asian reservoirs, lakes, waterways, and rivers. In particular, water-quality criteria are needed to assess the short- and long-term consequences of any chemical agent at any concentration in the aquatic reservoir environment and to provide guidelines, including specific pollutant levels, to form the basis of site-specific criteria and the subsequent setting of standards.

In practical environmental terms, USEPA (1976) stated that "water criteria specify concentrations in water of constituents which, if not exceeded, are expected to result in an aquatic ecosystem suitable for the higher uses of waters." In addition, when the criterion is used with protection in mind, it may be described as "designated concentration of a constituent that when not exceeded, will protect an aquatic organism, an aquatic community, or fisheries and aquaculture use or quality with an adequate degree of safety." To this end, several attempts have recently been made to derive criteria for the protection of aquatic life and its users in temperate waters (USEPA 1980) and tropical waters (Malaysia 1986; Tong et al. 1987). These attempts were made on firm scientific bases and the criteria-derivation procedures were performed in a rational, internally consistent, objective manner. In this paper, 40 organic chemicals, predominantly pesticides and herbicides (Table 1), have been selected for the derivation of water-quality criteria.

Materials and Methods

Many judgements and decisions must be made during the derivation of water-quality criteria. These judgements should be based on a thorough knowledge of aquatic toxicology and an understanding of defined guidelines (USEPA 1980) that consider practical, philosophical, and technical issues. The decisions should be consistent with the spirit of these guidelines and make the best use of available data.

Expression of Criteria

The criterion value for each chemical, whenever possible, is expressed in terms of a criterion maximum concentration (CMC) level and a 24-h criterion average concentration (CAC). This is in contrast to the common narrative and operational forms of criteria (AWRC 1979). The final acute value (FAV) estimated is taken as the CMC and should never be exceeded. The lowest value among the final chronic value (FCV), the final residue value (FRV), and the final plant value (FPV) is the 24-h CAC. Criterion values are always reviewed to see if they are reasonable.

Minimum Data Base

The minimum requirement is identified in four major areas: acute toxicity to tropical aquatic animals; chronic toxicity to aquatic animals; bioaccumulation factor with a maximum permissible tissue concentration; and toxicity to aquatic plants. The guidelines require that criteria be based on a minimum data base of exposure-effect relationships between pollutants and aquatic life occupying various trophic levels.

Acute Toxicity Data

Acute values in terms of 24- to 96-h effective concentration, 50% (EC_{50}) or lethal concentration, 50% (LC_{50}) were compiled, evaluated for relevance, and standardized in terms of exposure duration. As a result of inadequate information on the bioassay conditions in most available published documents, the standardization of acute values in terms of testing procedures (e.g., flow-through, renewal, or static conditions) is not possible. This causes of variations in the data base.

Table 1. Recommended water-quality criteria for tropical reservoirs and associated waterways.

	Present study		Malaysia (1986)[a]	
	CMC[b] (µg/L)	CAC[c] (µg/L)	CMC[b] (µg/L)	CAC[c] (µg/L)
Organochlorine pesticides				
Aldrin/Dieldrin	0.14	0.02	0.2	0.008
Benzene hexachloride	0.96	0.57	9.9	0.13
Chlordane	0.61	0.17	2.2	0.02
Dichlorodiphenyltri-chlorethane (DDT)	0.46	0.028	1.0	0.004
Endosulfan	0.004	-	0.01	-
Endrin	0.054	0.002	0.25	0.014
Heptachlor and heptachlor epoxide	2.4	0.06	0.91	0.06
Lindane	4.80	0.38	-	-
Organophosphorus pesticides				
Acephate	0.02	-	-	-
Diazinon	-	2.7	30.0	-
Dichlorvos	0.0004	-	0.02	-
Dimethoate	0.30	-	-	-
Disulfoton	-	0.13	-	-
Fenitrothion	580.0	0.12	0.05	-
Fenthion	0.021	-	-	-
Malathion	7.6	-	0.32	-
Parathion-methyl	0.45	-	3.7	-
Quinalphos	28.0	-	-	-
Trichlorfon	0.0004	-	0.001	-
Carbamate pesticides				
Aldicarb	0.16	-	-	-
Carbaryl	21.0	1.6	2.9	-
Carbofuran	6.3	-	0.01	-
Herbicides				
2,4-dichlorophenoxy-acetic acid	2100	33	450	-
2,4,5-trichlorophen-oxyacetic acid	350	-	850	-
Paraquat	330	-	1800	-
Fungicides				
Benomyl	-	1400	-	-
Carbendazim	-	340	-	-
Hexachlorobenzene	-	10	-	-
Thiophanate-methyl	-	8500	-	-

(continued)

Table 1. Concluded.

	Present study		Malaysia (1986)[a]	
	CMC[b] (µg/L)	CAC[c] (µg/L)	CMC[b] (µg/L)	CAC[c] (µg/L)
	Other organics			
Aniline	290	-	-	-
Benzene	14000	-	-	-
Cresols	5300	-	-	-
Phenol	2400	-	9900	-
Chlorinated phenols				
2-, 4-chlorophenols	1000	-	2200	-
Trichlorophenols	600	-	2500	-
Pentachlorophenol	14	7.5	60	-

[a]Includes freshwater and estuarine species.

[b]Criterion maximum concentration (CMC) is based on the final acute value.

[c]Criterion 24-h average concentration (CAC) is the lowest value among the final chronic value, the final residue value, and the final plant value.

Final Acute Value

If acceptable data on the acute toxicity of a pollutant to an appropriate aquatic species are available, criteria should be set to protect 95% of the tested families and all commercially, recreationally, and socially important species. A level of 95% was chosen so that FAVs would not be too high or too low. Therefore, the FAV is an estimate of the concentration of a pollutant corresponding to the cumulative probability of 0.05 in the acute toxicity values for the species within a genus with which acute toxicity tests have been conducted for that pollutant. The FAV was calculated using a computer program in basic language (Stephan et al. 1985) involving the following equations:

$$S^2 = \frac{\Sigma[(\ln \mathrm{GMAV})^2] - \{[\Sigma(\ln \mathrm{GMAV})]^2/4\}}{\Sigma(P) - \{[\Sigma(\sqrt{P})]^2/4\}}$$

where GMAV is the genus mean acute value, P is the cumulative probability for each GMAV [R/(N+1)], R is the rank assigned to the GMAV (lowest, 1; highest, N), and N is the total number of GMAVs in the data set.

$$L = \{\Sigma(\ln \mathrm{MAV}) - S[\Sigma(\sqrt{P})]\}/4$$
$$A = S(\sqrt{0.05}) + L$$
$$\mathrm{FAV} = e^A$$

The computation gives equal weight to four lowest genus mean acute values (GMAVs) that provide the most information. The other values, however, do have a substantial effect on the FAV.

Chronic Toxicity Data

The chronic value is the geometric mean between the lower chronic limit (highest tested concentration in an acceptable chronic test that did not cause a significant decrease from the control) and the upper chronic limit (lowest tested concentration in an acceptable chronic test that caused a significant decrease from the control). The acute chronic ratio is the ratio of specific acute value to a comparable chronic value for a particular species tested in the same water. The final acute/chronic ratio is the arithmetic mean of all the species mean acute/chronic ratios available in the data base.

Final Chronic Value

The FCV is an estimate of the concentration of a pollutant corresponding to a cumulative probability of 0.05 in the chronic toxicity values for a species within a genus with which chronic tests have been conducted for that pollutant. Like the FAV, a value of 95% was chosen so that the FCVs would not be too high or too low when compared with the data sets from which they are calculated. The FCV is usually obtained by dividing the FAV by the final acute/chronic ratio.

Final Residue Value

The FRV is the ratio of a maximum permissible tissue concentration of a pollutant to an appropriate bioaccumulation factor (BCF), where the BCF is the concentration of a pollutant in all the organs of an aquatic organism divided by the concentration in the water to which the organism has been exposed under a steady state. For lipophilic organics, the BCF is normalized in terms of the lipid content and further weighted with an average lipid content of edible species in the tropical waters. The maximum permissible tissue concentrations of the Malaysian food regulations (Malaysia 1985), the Australian Government (NHMRCA 1970), and the United States Food and Drug Administration (USFDA 1978, 1979), where available, have been adopted.

Final Plant Value

The "toxicity to plant" value is the concentration of a pollutant that decreases growth (measured by effective concentration (EC) on dry weight, chlorphyll, etc.) in a 24-96 h, or longer, test with an aquatic vasular plant. The FPV is the lowest plant value from a test in which the pollutant concentrations are measured. Data on toxicity to aquatic plants are included to determine whether plants are likely to be adversely affected by concentrations that should not adversely affect animals.

The derivation of numerical water-quality criteria (Fig. 1) involves some assumptions. First, it must be assumed that water quality has no effect on the pesticides and herbicides. Second, the site must be assumed to be a large, tropical Asian reservoir. Third, it must be assumed that the aquatic communities do not vary significantly and that the aquatic species are toxicologically similar. To minimize variation, data on native tropical biota are included in the data base.

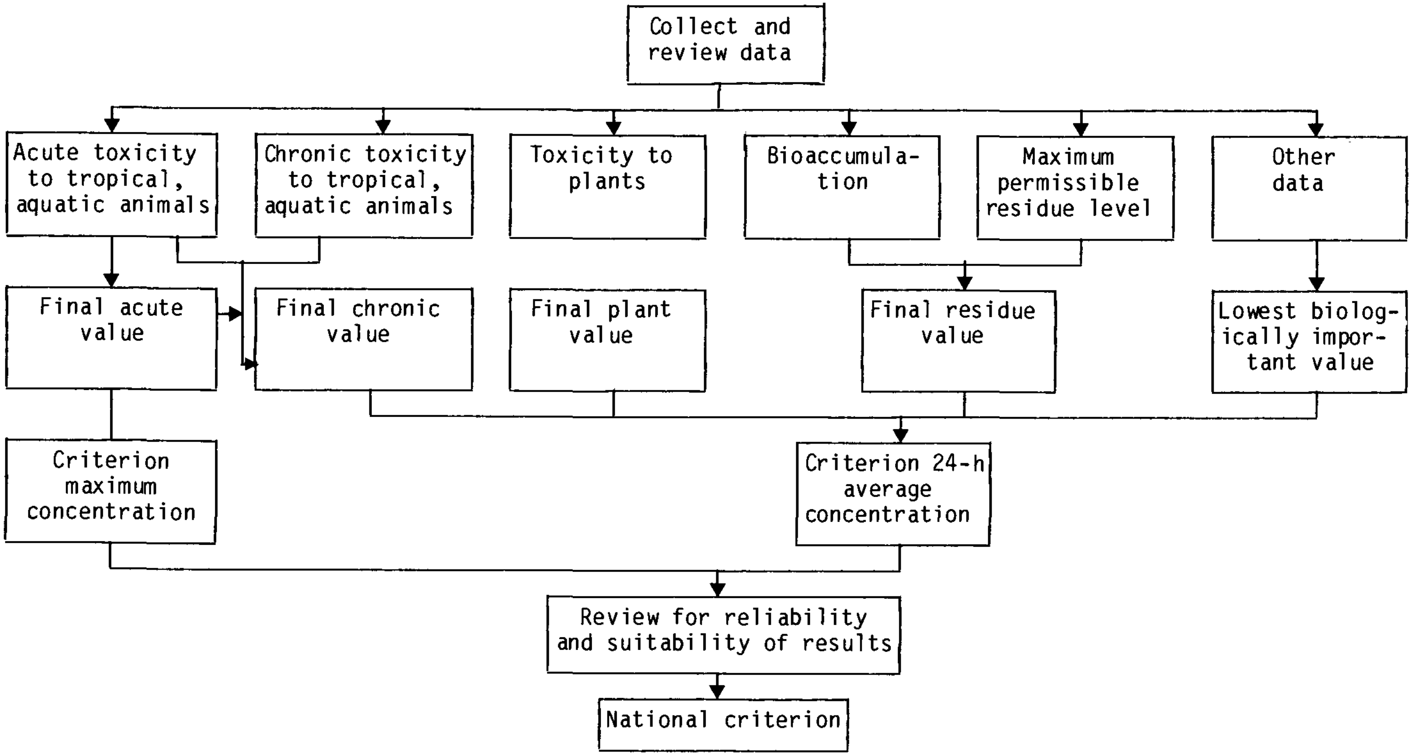

Fig. 1. Derivation of water-quality criteria for the protection of aquatic life and its users (modification from Stephan et al. 1985).

Results and Discussion

Criteria

The combination of a maximum concentration and a 24-h average concentration provides an appropriate degree of protection to aquatic organisms and their users from acute and chronic toxicity and bioaccumulation. The maximum concentration should never be exceeded to ensure the sustainability of aquatic resources. The 24-h average concentration should protect against the unacceptable effects of long-term exposure and ensure the production of marketable, consumable fishery products.

Based on available toxicological and bioaccumulation data, the CMCs of organochlorine pesticides range from 0.005 to 4.8 µg/L (endosulfan and lindane, respectively) (Table 1). The 24-h CACs are considerably less than the maximum concentrations. Being lipophilic and persistent in nature, organochlorine pesticides are highly bioaccumulative in the organs of aquatic organisms. The CACs are reasonably stringent to ensure the marketability and suitability of the fishery products.

The CMCs of organophosphorus pesticides vary considerably (Table 1). The CAC of fenitrothion is three orders of magnitude less than its CMC; thus, it is stringent enough to prevent an excessive bioaccumulation of fenitrothion in fishery products. There is not enough acute and chronic data available on diazinon and disulfoton in the present data base to calculate CMCs; however, the 24-h CACs of 2.7 and 0.13 µg/L, respectively, were estimated based on final residue values and are sufficiently reliable.

For herbicides, fungicides, and general organics, the criteria values are significantly higher and, therefore, less stringent than those for organochlorine, organophosphorus, and carbamate pesticides. For fungicides, there is insufficient data on acute and chronic toxicity and bioaccumulation, but available final plant values suggest considerably high 24-h CACs (Table 1).

For comparison, previously recommended water-quality criteria and standards for Malaysia are listed. With the exception of aldrin, dieldrin, and endosulfan, these values vary considerably with corresponding values in this study. The large discrepancies for most chemicals are due to differences in the data base, differential coverage, and inclusion of water, ecosystem, and biota types. There are some technical changes in the computational procedures adopted for this study in using the new method of Erickson and Stephan (1985) for calculating the FAC. This new method is an improvement over the previous version (USEPA 1980) used in the Malaysian case study.

Minimum Data Base

The minimum data base ensures the derivation of a good estimate of a criterion based on available data concerning toxicity and bioaccumulation, physical and chemical properties, and chemical structure. The accuracy of the criteria is further ensured because the available data must fit the defined framework as required in the guidelines. It is beyond the scope of this paper to list the minimum data bases for all 40 chemical agents; excellent reviews can be found in Pickering et al. (1983), Roush et al. (1985), Stehan et al. (1986), and Kline et al. (1987).

Research Needs

The derivation of water-quality criteria has inherent limitations and uncertainties. The computational procedures involve assumptions and statistical bias that are open to criticism (Stephan 1985). This is particularly true for tropical Asian reservoirs, where there are many gaps in the scientific knowledge and documentation and inconsistent analytical bioassay conditions. When deriving water-quality criteria, there should ideally be a complete set of quantitative exposure-effect relationships. This requires an evaluation of all environmental factors, species, aquatic communities, and pollutant exposure levels. However, this ideal situation cannot be met for even a single chemical agent, much less for the combinations of agents and environmental factors where synergistic and antagonistic effects interplay.

Table 2 presents acute toxicity data that are recognized to be incomplete or contentious. The available data on these chemicals should be reexamined and information gaps should be identified. Acute toxicity tests under flow-through conditions, in which the concentrations of highly volatile organic chemicals in the test solutions are measured, are more appropriate and, therefore, should be given priority by aquatic toxicologists. Chronic toxicity tests using tropical aquatic organisms and bioaccumulation tests under steady-state conditions (28-30 days exposure) are neglected research areas, resulting in a shortage of data on the effects of long-term exposure.

Criteria derivation for the protection of aquatic organisms and their users is a predictive exercise and a continuing process. Regular refinement is necessary and depends on the generation of more reliable data, improved analytical detection techniques, public feedback, and experience in the field. Although current information is sufficient for the derivation of water-quality criteria for the 40 selected chemicals, new data and ideas are necessary to occasionally improve the criteria. Confidence in a criterion usually increases as the amount of available, pertinent data increases.

Conclusions

Any approach to deriving water-quality criteria is acceptable as long as the procedures are performed in a rational, internally consistent, objective manner. From a practical point of view, the method in the USEPA guidelines ensures the sustainability of aquatic resources in tropical Asian reservoirs and protects the marketability of fishery products for human consumption. A review of the pertinent literature, however, reveals that much of the desired data is unavailable or that the available data may not fit a defined framework as required in the guidelines; therefore, additional data is needed. As new information is gathered and better rationales are developed, refinement of the water-quality criteria is necessary.

Table 2. Pesticides with inadequate data for water-quality criteria derivation.

	Species	MAVs (µg/L) available in the data set
	Organochlorine pesticides	
Methoxychlor	Carassius auratus	56
	Daphnia magna	3.6
Toxaphene	Gambusia affinis	77.5
	Carassius auratus	56
	Poecilia sp.	20
	Organophosphorus pesticides	
Chlorpyrifos	Carassius auratus	806
Diazinon	Channa punctatus	3100
	Saccobranchus fossilis	2270
	Poecilia sp.	976
Leptophos	Saccobranchus fossilis	22600
Methamidophos	Cyprinus carpio fingerlings	68000
	Tilapia nilotica	50940
Monocrotophos	Lebistes reticulatus	23000
	Macrobrachium lamarrei	1383
Parathion	Channa punctatus	2252
	Daphnia magna	0.59
	Daphnia carinata	0.41
Phosphamidon	Heteropneustes fossilis	280000
	Anabas scandens	62000
	Macrobrachium davanum	1812
Temephos	Saccobranchus fossilis	207000
	Macropodus cupanus	8558
	Aplocheilus lineatus	931
Thiometon	Saccobranchus fossilis	11393
	Carbamate pesticides	
Propoxur	Heteropneustes fossilis	5791
	Herbicides	
Amitrole	Gambusia affinis	2100000
	Cyclops vernalis	22100

(continued)

Table 2. Continued.

	Species	MAVs (µg/L) available in the data set
Asulam	*Ctenopharyngodon idella*	10000
Cyantryn	*Ctenopharyngodon idella*	58000
Dalapon	*Rasbora trilineata*	70277
	Poecilia reticulata	36494
Dicamba	*Gambusia affinis*	465000
Dichlobenil	*Ctenopharyngodon idella*	9400
Diquat	*Ctenopharyngodon idella*	1718000
	Carassius auratus	85000
Diuron	*Ctenopharyngodon idella*	31000
Endothall	*Carassius auratus*	372000
Glyphosate	*Chironomus plumosus*	55000
	Ctenopharyngodon idella	15000
Molinate	*Gambusia affinis*	16400
Picloram	*Gambusia affinis*	120000
	Daphnia magna	50378
Propanil	*Gambusia affinis*	9460
Terbutryne	*Ctenopharyngodon idella*	5800
	Fungicides	
Benomyl	*Lebistes reticulatus*	2552
	Daphnia magna	472
Carbendazim	Tadpole (*Rana hexadactyla*)	16000
	Daphnia magna	339
Thiophanate-methyl	*Lebistes reticulatus*	97591
	Daphnia magna	11802
	Acaricide	
Phenthoate	*Channa punctatus*	355
	Other organics	
Polychlorinated biphenyls (Aroclor)	*Hydra oligactis*	8277

(continued)

Table 2. Concluded.

	Species	MAVs (μg/L) available in the data set
2,4-dichloro-phenol	*Daphnia magna*	800
Pyrethroids	Catfish (*Clarias batrachus*)	0.052
Surfactants (MBAS/LAS)	*Daphnia magna*	99136

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LIMNOLOGY AND FISHERY POTENTIAL OF THE INDRASAROBAR RESERVOIR AT KULEKHANI, NEPAL

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Abstract *Limnological and biological studies carried out at the Indrasarobar Reservoir at Kulekhani, Nepal, show that the reservoir is eutrophic. The temperature at the reservoir water varied from 12 to 17°C during the winter and from 17 to 27°C during the summer. During the summer, the reservoir was stratified with a thermocline from 13 to 14 m, where the dissolved oxygen became very low during the summer. Acrossochailus hexagonolepis, Puntius chilinoides, and Schizothorax richardsoni are the indigenous species of the reservoir; A. hexagonolepis is dominant. Exotic species such as Aristicthys nobilis, Hypophthalmichthys molitrix, and Tor tor can now also be caught. Cage fish culture of H. moltrix has shown encouraging results.*

Nepal is a land-locked country with an area of 147,181 km^2. The country has nearly 6,000 rivers and rivulets, totaling about 21,000 km in length (Shrestha 1983), and 5,000 ha of natural lakes, some of which are dammed. In addition, there are a few multipurpose reservoirs with a water surface area of about 1,500 ha. Major plans are now underway in Nepal to develop 80,000 ha of reservoirs by the year 2000. At present, the per capita fish consumption in Nepal is 0.391 kg and a concerted effort is being made to increase reservoir fish production. The Indrasarobar Reservoir at Kulekhani is a newly impounded reservoir. This reservoir is being studied to evaluate potential fish production and to provide information that could be useful in future fisheries-development planning.

Materials and Methods

The limnology of the Indrasarobar Reservoir was studied from 1985 to 1987. The limnological parameters evaluated were temperature, pH, alkalinity, dissolved oxygen, transparancy, and hardness in relation to depth. Primary productivity was also estimated using the light and dark bottle method. The plankton communities are estimated quantitatively. A plankton net of 25 cm diameter and 73-µm mesh was used to collect the sample. All of these parameters were determined biweekly.

Monthly samplings of fish using multimesh gill nets with stretched mesh sizes of 25, 50, 75, and 100 mm were carried out at all stations. At one station, stratified sampling up to 30 m depth was carried out using a vertical gill net. The catch was separated by the different mesh sizes. The species composition and total weight-length distribution of each species landed were determined. Samples of each species were fixed in formalin for detailed studies of gonadal maturity and fecundity.

To evaluate the feasibility of cage fish culture in the reservoir, four series of experiments were set up. In these experiments, 2.5 m x 2.5 m x 2.0 m cages were used. This study was conducted using silver carp (Hypophthalmichthys molitrix) at four stocking densities: 448, 384, 150, and 90 g/m^3. A random sample of approximately 10% of the fish in each cage was taken monthly to evaluate growth rates.

Results

The Indrasarobar Reservoir was created by damming the Kulekhani River. The reservoir has a catchment area of 126 km^2, a surface area of 220 ha, a gross storage volume of 85 x 10^6 m^3, an effective storage volume of 75 x 10^6 m^3, and a drawdown of 53 m. The reservoir water was isothermal from November to March, and the water temperature ranged from 17 to 15°C. From April to October, the reservoir was stratified. The thermocline depth varied in these months: May, 13 m; July, 15 m; September, 40 m. The oxygen profile from December to February was orthograde; for the rest of the year, the oxygen profile was more or less clinograde. In May, June, and July, the dissolved oxygen content dropped sharply at 5 m and fell below 2 ppm at 20 m. The minimum secchi disc reading was 0.54 m in August; the maximum, 3.1 m in January. The mean secchi disc reading over the year was 1.9 m. Daily carbon production ranged from 350 mg/m^2 in October to 3100 mg/m^2 in April (average, 1415 mg/m^2).

Dominant phytoplankton included Navicula (29%), Oscillatoria (27%), Synedra (23.3%), Melosira (9%), and Peredinium (6.2%) (Table 1). Navicula, Oscillatoria, Synedra, and Melosira occurred year-round. The highest phytoplankton populations were observed in June, July, and September: 20.1, 10.3, and 15.6%, respectively. In the zooplankton population, rotifers accounted for 61.8% and copepods accounted for 27.6%. July, August, and September had the highest zooplankton populations with 24.0, 25.6, and 13.9%, respectively; December had the lowest, 1.9% (Table 2).

The Indrasarobar Reservoir has three indigenous fish species: katale (Acrossochailus hexagonolopis), karange (Puntius chilinoides), and asala (Schizothorax richardsoni). During the gill-net survey of 1985/86, a total of 4405 fish were caught. By number, the dominant species of this catch was P. chilinoides (52.3%). By weight, however, A. hexagonolopis accounted for 75% of the catch. Schizothorax spp. were the least dominant both in terms of number and weight (Table 3). The 1986/87 catch was similar to the 1985/86 catch except that introduced species (silver carp, H. molitrix; bighead carp, Aristicthys nobilis); mahseer, Tor tor; etc.) were evident. These species were not deliberately introduced into the reservoir, but escaped from the cages. The annual catch per unit effort (CPUE) was 0.12-1.7 g/m^2 per day in 1985/86 and 0.12-1.1 g/m^2 per day in 1986/87 (Fig. 1).

Table 1. Occurence (%) of phytoplankton in the Indrasarobar Reservoir from 1985 to 1987.

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual
Cyanophyta													
<u>Oscillatoria</u>	94.5	37.3	6.12	3.0	2.8	3.3	2.8	6.1	4.6	8.9	26.1	43.0	27.0
<u>Anabaena</u>	0.8	-	-	-	0.4	-	-	-	-	-	1.4	4.2	1.3
Chrysophyta													
<u>Synedra</u>	1.6	34.9	8.3	19.0	39.8	35.4	14.3	16.2	46.4	14.0	20.3	32.3	23.3
<u>Melosira</u>	1.3	5.8	0.4	2.4	35.0	32.7	27.0	24.3	3.6	26.7	7.2	3.2	9.0
<u>Navicula</u>	1.4	16.3	83.8	75.5	21.5	28.2	28.2	40.9	18.8	12.2	11.7	5.3	29.0
<u>Diatoma</u>	-	-	-	-	-	-	-	-	-	-	3.0	-	0.2
Chlorophyta													
<u>Staurustrum</u>	0.3	0.7	-	-	-	-	-	-	-	7.7	1.4	0.1	0.5
Pyrrophyta													
<u>Peridinium</u>	0.2	3.5	-	-	0.3	0.2	-	5.1	3.6	25.5	27.1	10.2	6.2
Others	-	1.5	1.4	0.1	0.2	0.2	27.9	7.5	23.0	5.1	2.8	1.7	3.5
Total[a]	10.3	3.3	15.7	7.9	6.9	4.8	4.2	2.6	7.1	3.7	7.4	20.1	

[a]Phytoplankton popluation as a percentage of the total carbon for a given month.

Table 2. Occurrence (%) of zooplankton in the Indrasarobar Reservoir from 1985 to 1987.

	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	Annual
Cladocera													
Daphnia	1.3	1.1	4.3	2.7	0.6	-	-	0.4	-	-	-	1.7	1.4
Rotifera													
Keratella	65.4	67.7	57.6	40.3	7.2	42.2	49.4	22.9	15.0	10.8	5.8	5.6	48.1
Polyartha	7.2	0.9	1.9	5.1	52.7	1.4	8.7	18.9	4.3	1.0	4.5	-	5.0
Asplachna	1.1	9.2	1.5	2.1	-	1.5	7.9	10.6	10.2	1.8	3.4	4.4	4.7
Pompholyx	0.9	2.9	4.5	3.0	5.4	-	3.2	2.2	44.4	7.5	4.3	0.7	4.0
Copepoda													
Cyclopes	21.1	14.1	25.7	39.1	13.2	11.3	7.1	11.9	15.5	65.6	61.3	66.2	27.6
Others	3.0	4.0	4.4	7.5	20.9	29.6	23.7	33.0	10.7	13.2	20.6	20.3	9.2
Total[a]	24.0	25.6	13.9	4.5	2.2	1.9	3.4	3.1	2.5	6.9	6.3	5.5	

[a]Zooplankton population as a percentage of the total carbon for a given month.

Table 3. Catch composition for 1985/86 and 1986/87.

Fish	1985/86 No.	1985/86 Weight	1986/87 No.	1986/87 Weight
A. hexagonolepis	2047 (46.5)	266 (75)	1213 (39.3)	141.4 (60.7)
P. chilinoides	2305 (52.3)	87 (24.5)	1765 (57.1)	66.2 (28.4)
Schizothorax spp.	52 (1.2)	1.66 (0.5)	59 (1.9)	1.4 (0.6)
Introduced spp.	- (-)	- (-)	52 (1.7)	24.1 (10.3)

Note: Values in parentheses are percentages of the total catch.

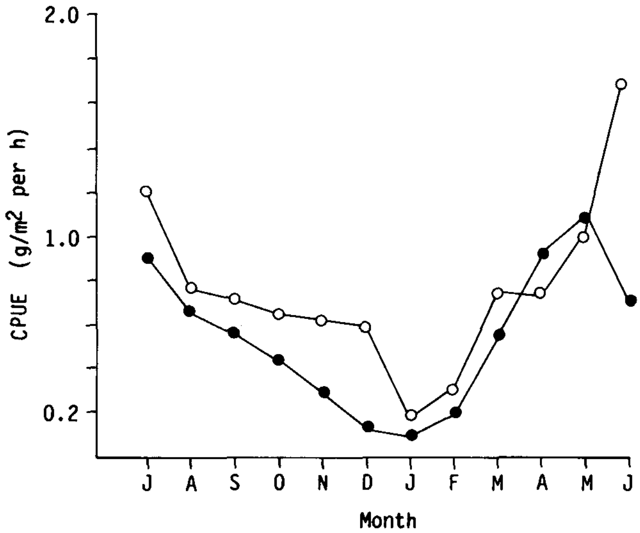

Fig. 1. Catch per unit effort (CPUE) at the Indrasarobar Reservoir for 1985/86 (○) and 1986/87 (●).

Cage Culture of Silver Carp

All cage-culture experiments were conducted over 165 days. Group 1 (stocking density, 448 g/m^3) and group 2 (stocking density, 384 g/m^3) silver carp grew from an initial weight of 160 g to 760 and 830 g, respectively (Fig. 2). Group 3 (stocking density, 150 g/m^3) and group 4 (stocking density, 90 g/m^3) grew from 15 g to 285 and 320 g, respectively (Fig. 2). There are significant differences in growth between groups 1 and 2 and groups 3 and 4.

Discussion

The preimpoundment river water temperature ranged from 14 to 18°C and atmospheric temperature ranged from 18.8 to 24.5°C (Nippon Consultant Group, Tokyo, Japan, personal communication). A minimum air temperature of -0.05°C in January and a maximum of 27.1°C in July

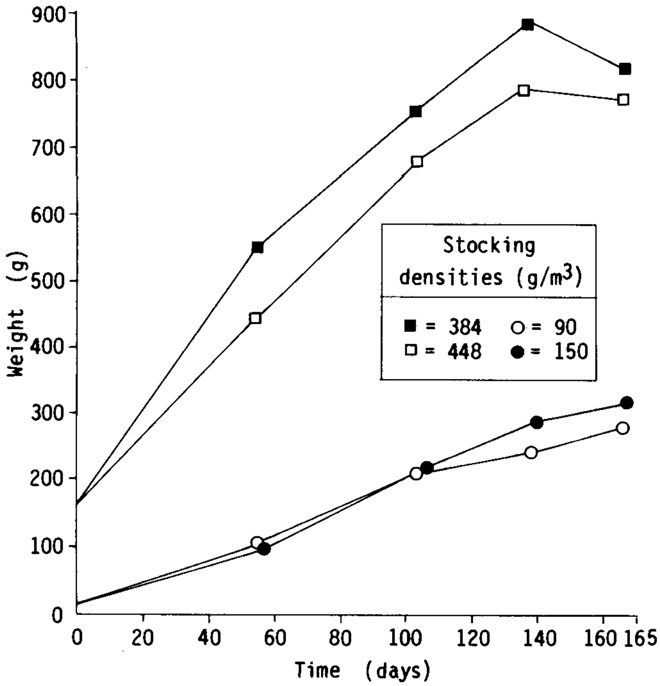

Fig. 2. Growth of silver carp in cage culture at four stocking densities and two initial stocking sizes.

was recorded in 1986. The thermocline during the summer months was below 10 m, providing a large volume of water suitable for fish.

A water body with 41-90 ppm total alkalinity has a medium to high productivity (Bennett 1970). Similarly, Cole (1975) quotes alkalinities of 51-67 mg/L to indicate a very productive water body. The annual mean alkalinity of the Indrasarobar Reservoir is 60 ppm, suggesting the reservoir can be categorized as productive.

According to Lind (1974), there is 1.98 mg plankton production per 1 mg carbon production. Therefore, with a mean daily carbon production of 1415 mg/m^2 (range, 350-3100 mg/m^2), the Indrasarobar Reservoir has a mean daily plankton production of 2801.7 mg/m^2. Lakes in Europe have been categorized as oligotrophic, mesotrophic, or eutrophic according to daily carbon production (OEDC 1968): oligotrphic, 65-290 mg/m^2; mesoeutrophic, 245-340 mg/m^2; eutrophic, 600 mg/m^2. With a daily carbon production of 350-3100 mg/m^2, this classification system also indicates that the Indrasarobar Reservoir is eutrophic. The clinograde oxygen profile of the reservoir also points to a eutrophic nature (Cole 1975).

The indigenous species katale (A. hexagonolepis) and karange (P. chilinoides) appear to have adapted to reservoir conditions. Asala (S. richardsoni), however, has almost vanished. The catch of introduced species (10% of total) indicates that the reservoir will support the growth of planktivorous fish. This is further supported by the results of the cage culture studies with silver carp (Fig. 2).

Conclusions

The data presented in this paper are of an interim nature as our studies on the Indrasarobar Reservoir are still in progress. In the future, detailed studies on cage culture with A. nobilis and H. molitrix will be carried out. All these studies will help to predict the fishery potential of the Indrasarobar Reservoir.

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DISCUSSION

The six papers in this session, of which five were presented, dealt with limnological aspects of reservoir fisheries. The fourth paper in this session, by Dr T.J. Pandian, was not presented.

The first paper focused on nutrient cycling in Parkrama Samudra, Sri Lanka. Dr Gunatilaka informed the workshop that this study is, so far, unique in Asian reservoirs. Some similar studies have been performed in Africa, however, where isotope studies indicated nitrogen deficiency as the limiting factor. In Parakrama Samudra, nutrient levels are directly influencing fishery output via primary production, influenced by the strong tropical diurnal rhythms. The internal nutrient flux depends on biological interactions and there are important external nutrient loadings from dissolved inputs and the feces of animals such as cormorants and buffaloes.

Following the two papers by Dr Vijverberg, the workshop attempted to reach a consensus recommendation on practical, accurate, and cost-effective plankton-monitoring technologies. The best method depends in part on the trophic status of the water body: if eutrophic, a volume-sampling technique should be used. This involves point sampling and requires a lot of work, especially if the water body is deep or extensive, requiring many depth samples per station and many stations.

The commonly used Ruttner and Kimmerer volume samplers have an inherent problem with turbulence when closing, causing large zooplankton (calanoid and cyclopoid copepods) to swim against the turbulence and escape. A nonmetallic volume sampler with a wide mouth such as the Patalas-Schindler sampler can reduce this error factor and is convenient in not requiring a winch or messenger. Consistency of method is required for longer time-series data. For fisheries, however, one is interested in the larger zooplankton, so a Patalas-Schindler apparatus is recommended.

The delegates recommended plankton nets. These are cheap, flexible, and adequate for many purposes, provided they are properly calibrated against a volume sampler. The much more expensive Clarke-Bumpus plankton sampler quantifies the volume of water filtered and at least one such apparatus should be available to each national or provincial fisheries management unit, to be available for borrowing by all stations.

The fourth paper focused on water-quality criteria in Asian reservoirs. Dr Yap informed the workshop that the criteria developed in her paper would be used on species that are commercially important in the marketplace. Acute toxicity is now determined in Malaysia by static bioassay techniques. Flow-through systems are now being developed for this purpose. At present, organochlorine pesticides, including DDT, are being used in Malaysia. These pesticides are at least partially regulated by the Department of the Environment and by pesticide boards. Although toxicological analysis is expensive, the Malaysian Food Regulation Act will enforce maximum levels of toxic chemicals.

The final paper in this session covered the limnological aspects of fishery reservoirs in Nepal. During the discussion, Mr Pradhan pointed out that the air temperatures in the valleys of Nepal are, in fact, fairly high; therefore, impounded water temperatures and productivity are also fairly high. To grow Chinese carp from 15 to 200 g requires 160 days. The economics of this level of production have not yet been studied, but growth rates are encouraging. With respect to local species, the growth of mahasir in ponds has been less than at the Kulekhani Reservoir, but these data are from only five captured fish. Mahasir are bred in Nepal by collecting sexually mature broodstock from the rivers. Females have not yet reached sexual maturity in pond conditions.

Blue-green algae are dominant in Nepalese fish ponds, with blooms occurring in April and May. These blooms are mainly *Anaboena* spp. without heterocysts, and fish kills are not expected. The Fisheries Development Section of the Ministry of Agriculture cooperates with the Zoology Department of Tribhuvan University and with the Freshwater Institute and the University of Manitoba in Winnipeg, Canada. At Tribhuvan University, students are making useful research contributions on benthos and gonadal development of fish.

General Discussion

The general discussion attempted to derive recommendations on a minimum set of physical, chemical, and biological parameters that can be measured at reasonable cost and will allow fisheries managers to predict yields of capture and culture fisheries. Measurements that have significance and utility for management include secchi disc readings, chlorophyll a, total sestonic weight (particulate organic carbon), total phosphorus, ammonia, and nitrite, and fish condition (gonad series and length-weight relationship). Also important are temperature variation, pH, conductivity, dissolved oxygen, alkalinity, water-level fluctuation, zooplankton-phytoplankton ratio, and dry weight of zooplankton. Dr Gunatilaka was asked to make available in written form the methodology for total phosphorus determination, useful for comparison with the Dillon-Rigler regression between mean chlorophyll a concentrations during the vegetative season and the maximal value for total phosphorus in the spring.

The workshop identified a strong need to encourage the manufacturers of limnology kits (e.g., Hach) to produce kits that are more appropriate to cage culture in the Third World. In particular, such kits should rely on first principles that are apparent to the user, rather than on black-box or cookbook routines of which the user has no understanding and that require resupply from the one manufacturer. Consumables for kits should be purchasable in the local currency.

There followed a discussion of institutions in reservoir fisheries management and research within a country and the division of labour and communications among these institutions. Researchers are not used to asking questions of an applied nature that will be of interest to industry, and there tends to be poor communication between, for example, university researchers and fishery managers. In addition, fishery managers and their officers are often unable to collect routinely the sophisticated data that will be useful to the basic research scientist.

Within the region there is a need for recommended standard measurement and techniques, so that data is reliable and comparable. In a given sitation, one strategy is to take many different measurements in the first 1 or 2 years and to look for correlations that can the simplify the data requirement in the future.

Session III

Biological and Resource Aspects

SOME BIOLOGICAL ASPECTS OF THE PREDOMINANT FISH SPECIES IN THE JATILUHUR RESERVOIR, WEST JAVA, INDONESIA

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Abstract *Five of around 20 autochthonous fish species, i.e., "hampal" (Hampala macrolepidota), "jambal" (Pangasius pangasius), "tagih" (Puntius bramoides), "tawes" (Puntius gonionotus), and "lalawak" (Puntius bromoides) are the predominant species in the 8300-ha, multipurpose Jatiluhur Reservoir in West Java, Indonesia. Some biological aspects of these species, i.e., distribution, food and feeding habits, spawning, growth, and population dynamics are described. The effects of the extensive fluctuations in water level on these biological aspects are evaluated. The reservoir, estimated to have an average annual fish production of 27.8-30.2 kg/ha and a present total production of 451.9 t/year, seems to have reached its optimum level of production. A knowledge of the biological aspects of the predominant species of the reservoir is of prime importance to ensure effective fishery management.*

The Jatiluhur Reservoir, also known as the Juanda Reservoir, was formed by damming the Citarum River. Construction of the dam was completed in 1965. It is a multipurpose reservoir primarily intended for agricultural and hydroelectric-power purposes and, secondarily, for fisheries. The reservoir is 107 m above sea level and surrounded by a limestone chain of mountains. It has a maximum water surface area of 8300 ha, a maximum depth of 95 m, an average depth of 36.4 m, and an average slope of 30% (Anon. 1974). Being a multipurpose reservoir, the water level fluctuates greatly. The highest and lowest water levels may differ by 20 m.

Fisheries activities started as soon as the reservoir was formed in 1965. By 1985, there were 350 full-time and 150 part-time fishermen. Gill nets, long lines, cast nets, lift nets, and scoop nets are utilized. Under stable conditions, the average annual production of the reservoir is 27.8-30.2 kg/ha (Kartamihardja 1985). The present total production (451.9 t/year) has likely reached an optimum level (Kartamihardja 1987).

The reservoir contains at least 20 autochthonous species and 8 exogenous species introduced for stocking purposes (Kartamihardja 1987). The fish population was initially dominated by predatory species. Efforts were made to improve the predator/prey ratio by stocking the reservoir with herbivorous "tawes" (Puntius gonionotus).

The efforts have improved the predator/prey ratio from 65:35 in 1982/83 to 55:45 in 1984/85 to 45:55 in 1985/86 (Kartanihardja 1985).

The fish species that dominate and contribute substantially to the production of the reservoir are "hampal" (Hampala macrolepidota), "tawes" (Puntius gonionotus), "tagih" (Macrones nemurus), "lalawak" (Puntius bromoides), "jambal" (Pangasius pangasius), and "nila" (Oreochromis niloticus). Therefore, a knowledge of the biological aspects of these species is important for the rational management of the reservoir. This paper describes the major biological aspects of these species and suggests methods of applying this knowledge to the management of the reservoir.

Biological Aspects

Hampal

Hampal (Hampala macrolepidota) are responsible for the major portion of the total fish catch of the reservoir. They are carnivorous. In the Ogan Komering River and Lake Cangkuang in Sumatera, they feed on fish, prawns, insects, and larvae (Vaas et al. 1953). In the reservoir, the main food of hampal measuring 185-507 mm and weighing 90-1420 g are fish, crustaceans, and insects (Rahardjo 1977). Hampal weighing 115-180 g feed mainly on Daphnia sp., Macrobrachium sp., fish, insects, and insect larvae (Tjahjo 1985). The predatory hampal becomes piscivorous when it reaches 200 mm.

Like other cyprinids, adult hampal migrate upstream to spawn at the beginning of high water (Soehardi 1971). In the reservoir, hampal spawn at the beginning of the rainy season, i.e., September-October (Achmad 1970) or August-October (Rahardjo 1977). The fecundity of hampal measuring 206-507 mm ranges from 5,398 to 56,109 eggs: $\log F = -1.4039 + 2.2056 \log L$ ($r = 0.78$), where F is the fecundity (eggs) and L is the total length (millimetres). Hampal growth is isometric (Table 1); therefore, at the same total length, the female hampal tends to be heavier than the male.

Jambal

Jambal (Pangasius pangasius) grow well in the reservoir and their population has increased over the last 10 years. It has been spawned using the hypophyseal technique (Ondara 1986). Using the "relative importance index" (Kartamihardja 1977), jambal measuring 125-795 mm and weighing 30-3700 g were found to feed mainly on crustaceans, insects, molluscs, rotifers, algae, and, rarely, small fish, i.e., "teri" (Chela oxygastroides) and "paray" (Rasbora argyrotaenia). In the Ogan Komering River of southern Sumatera, jambal feed on aquatic plant material, insects, insect larvae, and bottom worms (Vaas et al. 1953). In the estuarine Matlas and Kulti in India, jambal feed on the remains of organisms, aquatic insects, molluscs, crustaceans, isopods, and amphipods and are not piscivorous (David 1963). This diverse variety of foods seems to indicate that jambal are mainly omnivorous, but may also feed on small or dead fish.

In the Hooghly River in India, the ovaries of jambal begin to mature when the fish reaches a length of 790 mm (David 1963). In the

Table 1. Length-weight relationships of the six predominant species of the Jatiluhur Reservoir.

Species	n	Length (L) (mm)	Weight (W) (g)	L-W relationship	r	Growth[a]
Hampala macrolepidota[b]						
Male	-	185-340	90-500	$W = (2.33 \times 10^{-5})\ L^{2.8821}$	-	Isometric
Female	-	198-507	100-1420	$W = (3.18 \times 10^{-5})\ L^{2.8242}$	-	Isometric
Pangasius pangasius						
Male	-	125-560	40-1250	$W = (1.41 \times 10^{-5})\ L^{2.9204}$	-	Isometric
Female	-	145-795	30-3700	$W = (1.78 \times 10^{-5})\ L^{2.8814}$	-	Isometric
Macrones nemurus[c]	100	145-550	35-3450	$W = (4.90 \times 10^{-6})\ L^{3.2099}$	0.988	Allometric
Puntius gonionotus	150	145-405	40-1405	$W = (4.13 \times 10^{-6})\ L^{2.2311}$	0.995	Allometric
Puntius bromoides	106	100-260	20-260	$W = (5.53 \times 10^{-5})\ L^{2.7592}$	0.953	Allometric
Oreochromis niloticus	63	135-440	50-2000	$W = (3.69 \times 10^{-5})\ L^{2.8992}$	0.993	Isometric

[a]Growth is isometric if factor b in the L-W relationship ($W = aL^b$) equals 3; if factor b does not equal 3, growth is allometric.

[b]Source: Kartamihardja (1977).

[c]The condition factor (weight/length^3) of tagih, especially the female fish, varies from 0.404 to 0.556 depending on the season.

reservoir, however, the ovaries of jambal measuring 795 mm and weighing 3700 g are only at stage III of gonadal maturation; gonadal maturity is attained when the fish measures 1000 mm and weighs over 6000 g (Kartamihardja 1977). The fish are believed to spawn in the upper area of the reservoir in the deeper part of the Citarum River around the beginning of the rainy season (Anon. 1973; Kartamihardja 1977). The mature brood fish migrate to the Citarum River to spawn and their larvae and fry are washed downstream into the reservoir by the current. The male/female ratio at the beginning of rainy season is 1:1. Jambal growth is isometric; therefore, at the same total length, the female jambal tends to be heavier and larger than the male.

Tagih

Eight species of Macrones have been recorded in the rivers and lakes of Indonesia. In Kalimantan and southern Sumatera, tagih (Macrones nemurus) are cultured in cages in rivers. In the Jatiluhur Reservoir, Macrones nigriceps and Macrones micracanthus are found in addition to tagih. Tagih are found mainly in the upper area of the reservoir around the Citarum River inlet.

The food and feeding habits of tagih in the reservoir have been studied by Sastrawibawa (1979). This species feeds on crustaceans, fish, and insects. In the Kapuas River in Kalimantan, Vaas et al. (1953) reported that tagih fed on cladocerans, copepods, rotifers, insects, insect larvae, crustaceans, fish, and crabs, making tagih an omnivorous predator. In the Jatiluhur Reservoir, studies indicate that tagih are carnivorous and predatory.

The long genital papilla of male tagih distinguishes it from the female, which possesses a round papilla. In the reservoir, the fish spawn from October to March in the Citarum River or in the upper, muddy-bottom region of the reservoir; the male/female ratio is 1:1. The eggs are buried in the mud. A fecundity of 64,769 eggs of 0.5-1.7 mm diameter has been observed (Sastrawibawa 1979). Female fish reach maturity at a length of around 320 mm (Djajadiredja et al. 1977). Tagih growth is allometric (Table 1).

Tawes

Tawes (Puntius gonionotus) is an important species of the rivers and lakes of Java, Sumatera, and Sulawesi. It is also a common cultured species. The fish can live up to 800 m above sea level at a minimum temperature of 15°C; its optimum temperature range is 25-35°C (Djajadiredja et al. 1977).

In the reservoir, the fish are derived from both the Citarum River and stocking. The species has successfully adapted to the environmental conditions of the reservoir and is becoming the most dominant species in the reservoir. Tawes are naturally herbivorous. In the reservoir, they feed on plant and animal matter, detritus, and planktonic copepods (Cyanophyceae and diatoms). Smaller tawes feed mainly on unicellular algae and zooplankton.

Like most other cyprinids, tawes spawn at the beginning of the rainy season in the upper, shallow areas of the reservoir, especially in areas that were dry during the previous low water. Sexually mature tawes are usually found from August to November. Tawes grow allometrically (Table 1).

Lalawak

Lalawak (Puntius bromoides) in the reservoir are derived from the Citarum River. They can reach a length of 400 mm and a weight of 500 g. The fish caught by fishermen usually range from 145 to 300 mm and from 50 to 400 g.

Sutardjo (1980), who studied the feeding habits of lalawak in the Jatiluhur Reservoir based on an "index of prepondarance," found that the fish feed primarily on detritus and plant matter and secondarily on crustaceans, insects, Bacillariophyceae, "particulate matter," protozoans, and Chlorophyceae. Based on the abundance of food types, the fish are omnivorous. The index of prepondarance indicates that the fish feed mainly on plants in September and December and on detritus in October.

Like tawes, lalawak spawn at the beginning of the rainy season (August) in the upstream areas of the reservoir that have just been submerged by high water. Lalawak grow allometrically (Table 1).

Nila

Nila (Oreochromis niloticus) were first imported in 1969 and are now found throughout Indonesia. The fish were introduced into the reservoir in 1972 and, in 1976, they accounted for 0.2% of the total fish catch. Nila grows fast and reach a maximum length of 500 mm and a maximum weight of 3000 g.

Nila are omnivorous, feeding on detritus, phytoplanktonic diatoms and Chlorophyceae, zooplanktonic copepods, cyclopods, and soft plant particulate matter. The most dominant food groups are detritus and plankton.

In the reservoir, sexually mature nila are usually found from July through September and especially in August. Fecundity ranging from 1950 to 4550 eggs has been recorded for a female nila measuring 200-260 mm. The oval eggs were 2.95-2.98 mm in diameter and 1.95-2.30 mm in width. Sexual maturation may occur when the fish reaches a total length of 190 mm. In the reservoir, their spawning grounds have been noted at Ubrug, Pegadungan, Sukasari, Cimanggu, Cidadap, and Warung Jeruk. During high water, schools of nila fry have frequently been noted in these areas. Nila grow isometrically (Table 1).

Fish Population Dynamics

The biological aspects of the predominant fish species are reflected in the population dynamics of the reservoir. During the early life of the reservoir, the total fish production was as low as 41 t/year. Three years after the creation of the reservoir, total fish production increased to 310 t/year. In subsequent years, production decreased, probably because of a decreasing food supply and the failure of certain fish species to adapt to the environmental conditions of the reservoir, retarding growth and propagation. Only 6 of the 20 autochthonous fish species initially inhabiting the reservoir, i.e., hampal (Hampala macrolepidota), tagih (Macrones nemurus), jambal (Pangasius pangasius), tawes (Puntius gonionotus), lalawak (Puntius bromoides), "genggehek" (Mystacoleucus marginatus), and the small fish species paray (Rasbora argyrotaenia), teri (Chela oxygastroides), and "bobosok" (Stigmatogobius bimaculatus), have been found to grow and propagate well in the reservoir. "Arengan" (Labeo crysophaekadion), which, up to 1979, were caught in appreciable numbers, are no longer among the predominant species of the Jatiluhur Reservoir.

The ratio of predator fish (P) to prey fish (F) was probably also responsible for the decrease in fish production. Subsequent stocking of the reservoir improved the P/F ratio from 65:35 in 1982/83 to 45:55 in 1985/86. A balanced P/F ratio was expected because of the increasing prey-fish populations of tawes and nila. Tawes grow and adapt well in the reservoir probably because of their ability to feed on detritus.

Biological Management

Knowledge of the biology of the predominant fish species in the reservoir is important to ensure rational fishery management. Based on this biological knowledge, certain management measures can be implemented to maintain the maximum sustainable yield of the reservoir and conserve resources. Such measures may include restocking of the reservoir to maintain a balanced P/F ratio, controlling fishing seasons as related to spawning seasons, controlling types and mesh sizes of fishing gear, and establishing natural fish reserves to protect brood fish and their fry. All of these measures have been applied at the Jatiluhur Reservoir with promising results. However, the biological behaviour of the fish species, the population dynamics, and the environmental conditions of the reservoir must be closely monitored to ensure continued effective management of the reservoir.

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GROWTH OVERFISHING: A POTENTIAL DANGER IN THE SRI LANKAN RESERVOIR FISHERY

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Abstract *The status of Oreochromis mossambicus was investigated in the fisheries of five man-made reservoirs in Sri Lanka. A declining trend in the mean landing size of O. mossambicus over the last three decades, at least in the case of one reservoir, indicates overexploitation. The data suggested that the mean body condition of O. mossambicus, measured as the theoretical weight of a 20-cm individual (W_{20}) is negatively correlated ($p < 0.05$) to the percentage of undersized (20 cm) O. mossambicus in the commercial catches. The low stock abundance of O. mossambicus in some reservoirs of which the body condition is poor is possibly due to catching individuals before they attain a reasonable size. This situation, called "growth overfishing" is a potential danger in most of the reservoirs in Sri Lanka. The importance of maintaining a minimum catch size (20 cm) of O. mossambicus is discussed.*

The low cost and high potential for protein production of freshwater fisheries in rural communities, have compelled Sri Lanka to focus on the development of inland fisheries. The inland fisheries of Sri Lanka are almost entirely confined to man-made reservoirs that were constructed for irrigation and hydroelectric purposes.

Since its introduction to Sri Lanka in 1952, Oreochromis mossambicus (Peters), an exotic cichlid, has played a major role in inland fish production. De Silva (1985a) has shown that O. mossambicus accounts for between 56 and 99% of the total fish yield in individual reservoirs and that, in most reservoirs, the percentage contribution of this species to production is more than 70%. Although invaluable contributions have been made to the development of reservoir fisheries in Sri Lanka (Fernando 1971, 1977; De Silva and Fernando 1980; De Silva 1983, 1985a), the information on reservoir fisheries management is inadequate. A declining trend in the mean landing size of O. mossambicus has been recorded in Parakrama Samudra, a Sri Lankan man-made reservoir (De Silva 1985a). However, in Sri Lankan reservoirs, no attempt has been made to investigate the effect on fish production of catching small, young fish ("growth overfishing") (Gulland 1983). This paper highlights and discusses the potential danger of growth overfishing in the reservoir fisheries of Sri Lanka.

Table 1. Some morphometric characters of the reservoirs, catch per unit effort (CPUE) for all species as well as *Oreochromis mossambicus* (*O.m.*), and sampling periods in individual reservoirs.

Reservoir	Surface area (ha)	Depth (m)	CPUE (kg/net piece per day)		Sampling period
			All species	*O.m.*[a]	
Kaudulla	2537	9.1	1.624	0.576(35.5)	Apr. 1986 - Feb. 1987
Minneriya	2560	11.7	1.487	1.012(68.1)	July 1986 - Feb. 1987
Parakrama Samudra	2662	7.6	0.941	0.659(70.0)	Feb. 1985 - Jan. 1986
Pimburettewa	834	7.3	1.339	1.205(90.0)	Feb. 1985 - Jan. 1986
Tabbowa	462	4.0	1.145	0.438(38.2)	July 1986 - Feb. 1987

[a]Values in parentheses represent the percentage of the CPUE accounted for by *O. mossambicus*.

The Fisheries

The five reservoirs studied are located in the dry zone of Sri Lanka, receiving less than 195 mm/year of precipitation (Table 1). Except in Pimburettewa, the mesh sizes of gill nets used range from approximately 76 to 140 mm. Mesh sizes below 102 mm are not permitted in the Pimburettewa fishery according to the regulations imposed by the fishermen (Amarasinghe 1987). In Parakrama Samudra, however, even some 69-mm mesh gill nets are used sporadically. In all the reservoirs, some fishermen beat the water with wooden poles from their nonmechanized, fiber glass, outrigger canoes to drive the fish toward the gill nets. This fishing technique is called "water beating" (Amarasinghe and Pitcher 1986). In Tabbowa, 76-mm mesh trammel nets made with 150-mm mesh outer net screens are used in the water-beating technique. In addition to this method, during the low-water months, the water beating is practiced in shallow areas of the reservoir using monofilament, 102-mm mesh gill nets and 76-mm mesh gill nets whose height exceeds the water depth in the fishing area. These fishing methods are more efficient than normal gill netting. During low-water seasons, beach seining, which is illegal, is carried out in Minneriya Reservoir in addition to normal gill netting and the water-beating technique.

Materials and Methods

Monthly length-frequency statistics of O. mossambicus (total length to the nearest 0.5 cm below actual length) were collected from the fish-landing sites of the five reservoirs studied (Fig. 1). The catches of all the practiced fishing methods were accounted for in the length-frequency data. Sampling periods in individual reservoirs varied (Table 1).

Catch per unit effort (CPUE) values for normal gill net fisheries are used to compare stock abundances in individual reservoirs (Table 1). Amarasinghe and Pitcher (1986) have shown that the best formulation of CPUE for the gill net fishery of Parakrama Samudra is catch per net piece per day; therefore, the same version of CPUE, which permits effort to be standardized, was used for all the reservoirs in this study.

Samples of O. mossambicus obtained from the commercial catches of Parakrama Samudra (148 fish) and Tabbowa (90 fish) during different months of the study period, packed in ice, were taken to the laboratory to determine total length (to the nearest 0.1 cm), somatic weight (to the nearest 0.1 g), and sex. The gonads of the females were grouped into six maturity stages according to Chandrasoma (1980). The percentage of mature females (stage III and above) in each length group (centimetre) of the Parakrama Samudra and Tabbowa reservoirs were calculated and the length at 50% maturity (L_m) was determined. The results are compared with data from three other Sri Lankan reservoirs (Table 2).

Oreochromis mossambicus enters the fishery in its 3rd year De Silva 1985b; Amarasinghe 1977). Fish smaller than 20 cm, which corresponds to approximately 2 years of age (De Silva and Senaratne 1987; Amarasinghe 1987), were considered undersized.

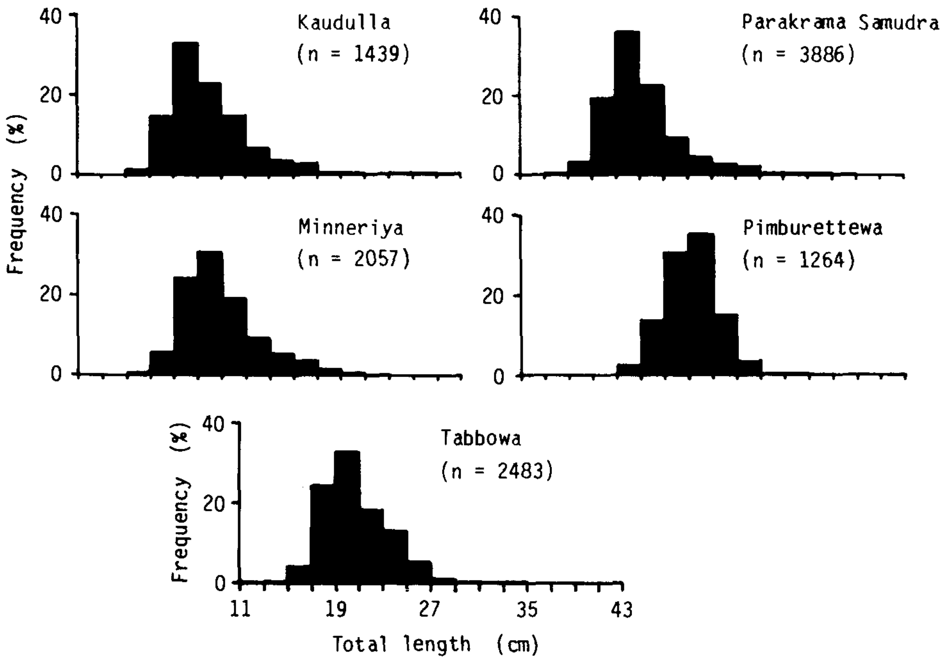

Fig. 1. Length-frequency distribution of O. mossambicus in the commercial catches of five Sri Lankan reservoirs (n, number of fish measured).

Table 2. Body condition (W_{20}), maturity size (L_m), and percentage of Oreochromis mossambicus (O.m.) below 20 cm in the commercial catches of different reservoirs.

Reservoir	W_{20} (g)	L_m (cm)	% O.m. < 20 cm
Kaudulla	143.4[a]	21.0[b]	48.4
Minneriya	139.8[a]	19.5[b]	30.2
Parakrama Samudra	138.7	16.1	58.6
Pimburettewa	160.5[a]	20.5[b]	2.5
Tabbowa	138.2	15.5	61.7

[a]Source: De Silva (1985c).
[b]Source: De Silva (1986).

Results

Logarithmic total length - somatic weight relationships were computed for the O. mossambicus populations in Parakrama Samudra and Tabbowa. The relationships in both reservoirs were significant at the

0.1% level and are described by the following equations:

Parakrama Samudra

$$\log_{10}W = \log_{10}0.028 + 2.841 \log_{10}TL \quad (r = 0.971)$$

Tabbowa

$$\log_{10}W = \log_{10}0.032 + 2.792 \log_{10}TL \quad (r = 0.945)$$

where W is the somatic weight (grams) and TL is the total length (centimetres). The body condition of O. mossambicus in each of these reservoirs was expressed as the mean theoretical weight of a 20-cm individual (W_{20}), calculated using the above regression equations.

The mean body condition (W_{20}) of O. mossambicus in different reservoirs was negatively correlated to the percentage of undersized (<20 cm) O. mossambicus in the commercial catches according to the following relationship:

$$Y = 157.73 - 0.3381X \quad (r = -0.8804, p < 0.05)$$

where Y is W_{20} (grams) and X is the percentage undersized fish in the commercial catches. This relationship is only based on five reservoirs (df = 3). Therefore, although a trend is suggested, more data are required from other reservoirs. No significant relationship was apparent between L_m and the percentage of undersized O. mossambicus (Table 2).

Discussion

Oreochromis mossambicus was the dominant fish species in Sri Lankan reservoirs until the late 1970's (De Silva 1985a). This study indicates that the contribution of this species is now less significant in Kaudulla and Tabbowa (Table 1). When the overall fish production is taken into account, Oreochromis niloticus, another exotic cichlid species, is the major species in these reservoirs (personal observation). The reason for the dominance of O. niloticus in these two reservoirs is unclear. Perhaps, after stocking with O. niloticus fingerlings, the conditions in these reservoirs were more favourable to this species. Chandrasoma (1986) reported that in Sorabora Wewa, another man-made reservoir in the dry zone of Sri Lanka, O. niloticus became the dominant species 4 years after its introduction. After this reservoir was drained a few years ago, it was refilled and stocked with O. niloticus fingerlings.

The low CPUE for O. mossambicus in Parakrama Samudra and Tabbowa (Table 1) indicates a low stock abundance for this species. In 1957, when the less-efficient cotton gill nets were in wide use (Indrasena 1965), the mean landing size of O. mossambicus in Parakrama Samudra was 34.2 cm; by 1978, it had declined to 21.8 cm (De Silva and Fernando 1980). The present study has revealed a further decline to 21.0 cm in 1985-86. This confirms the suspected overexploitation of O. mossambicus. However, in shallow water bodies, the cichlids are said to maintain their reproductive capacity at its original level by changing their growth rate and maturity size, even at high mortality levels (Iles 1973). Hence, even at high fishing rates, recruitment failures may not result in O. mossambicus popluations in shallow reservoirs in Sri Lanka. The von Bertalanffy growth constant (K) of O. mossambicus populations in 11 Sri Lankan reservoirs ranges from 0.32 to 0.7 (De Silva and Senaratne 1987; Amarasinghe 1987), indicating a varying growth rate from reservoir to reservoir.

Lowe-McConnell (1982) states that body condition and maturity size are indices of stunting in cichlids. De Silva (1985c) and the present study found that the body condition (W_{20}) of O. mossambicus populations in some major reservoirs of Sri Lanka ranged from 138.2 to 167.8 g. In addition, the mean maturity size of female O. mossambicus in Parakrama Samudra has declined from 17.5 cm in 1978 (De Silva and Chandrasoma 1980) to 16.1 cm in 1985 (Table 2). From the information on growth rate, body condition, and maturity size, it is evident that O. mossambicus populations in some Sri Lankan reservoirs, if not stunted, are in danger of becoming stunted.

"Recruitment overfishing" (Gulland 1983) is unlikely for O. mossambicus in shallow, Sri Lankan reservoirs because the stocks can withstand high fishing mortality rates through their reproductive resilience. The problem of overexploitation of O. mossambicus populations, at least in Parakrama Samudra, therefore, is likely due to growth overfishing. Of the five reservoirs studied, low stocking densities and poor body conditions of O. mossambicus are found in Parakrama Samudra and Tabbowa. The relationship between body condition and percentage of undersized O. mossambicus in commercial catches (Table 2) indicates that a reduction in landing size results in poor body condition.

Conclusions

Catching smaller O. mossambicus has led to a depletion of fish stock sizes in some reservoirs and is a potential danger in other reservoirs in Sri Lanka. Unless measures are implemented to enforce a minimum landing size for O. mossambicus, a combination of increasing demand for freshwater fish and growth overfishing may result in a drastically reduced fish production. According to De Silva (1985a), the fishing pressure in Parakrama Samudra (9.9 craft days/ha per year) is lower than that of Pimburettewa (23.4 craft days/ha per year). Nevertheless, Amarasinghe (1987) has shown that overexploitation is not evident in the Pimburettewa fishery, where the minimum mesh size for a gill net is 102 mm. Therefore, it appears that O. mossambicus populations in Sri Lankan reservoirs can withstand high fishing intensities if the mesh size of the gill nets is maintained at or above 102 mm. Also, gill net selectivity experiments in Parakrama Samudra (Amarasinghe 1988) have indicated that the minimum mesh size for the gill net should be increased from 76 to 102 mm for optimal utilization of O. mossambicus. The minimum landing size of O. mossambicus should be maintained at or above 20 cm through mesh-size regulations.

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NONCONVENTIONAL FISH RESOURCES IN SRI LANKAN RESERVOIRS

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Abstract *In most of tropical Asia (approx. 15°N to 15°S), reservoir fisheries are mostly dominated and dependent on exotics. Various reasons have been attributed to the success of exotics in tropical Asian reservoir fisheries. Experimental fishing with multimesh gill nets in Sri Lankan reservoirs have indicated the presence of populations of appreciable size of indigenous minor cyprinids. Studies have shown that these minor cyprinid populations could be exploited without any apparent detrimental effects on the existing commercial fishery, based predominantly on the exotic cichlid, Oreochromis mossambicus. The initial multimesh gill net trials were extended when commercial-size nets (50 m by 1.5 m) of two mesh sizes (15 and 30 mm), shown to be suitable for the exploitation of minor cyprinids, were used by the survey team and commercial fishermen. The results have confirmed the earlier findings. The limitations of a fishery based on minor cyprinids and the potential of introducing two-tiered exploitation methods are discussed.*

In Southeast Asia in general, there is a paucity of lacustrine water bodies as compared with the rest of the world (Fernando 1980). This paucity is reflected in the fish fauna of the region (Fernando and Furtado 1975; Fernando 1980), with only 20 lacustrine species as compared with an estimated 1600 riverine species. The number of lacustrine species in the region is dismally low when compared with tropical regions in the rest of the world.

Reservoirs or man-made lakes have existed for over 6000 years. In some countries of Southeast Asia, e.g., Sri Lanka, man-made lakes have been an important component of ancient civilizations (Fernando and De Silva 1984; De Silva 1988a). The development of fisheries in man-made lakes in the region, however, has been recent (Fernando 1977; Bhukaswan 1985; De Silva 1985). Moreover, most of these fisheries have developed around exotic cichlids, which were introduced into the region in the late 1940's. The success of these exotics has been mostly attributed to the paucity of the lacustrine fish fauna in the region (Fernando 1980; Fernando and Holick 1982); in effect, there are only a few reservoir fisheries in the tropics of Southeast Asia that are dominated by indigenous species. Some Thai reservoirs, for example, have indigenous species such as Barbus gonionatus, Cirrhinus jullieni, and Osteochilus sp. as major constituents (Chookajorn and Bhukaswan, this volume).

This paper reviews the recent studies on alternative, indigenous fish resources in Sri Lankan reservoirs. The development of such fisheries is discussed.

Present Status

The present status of Sri Lankan reservoir fisheries has been documented by Fernando and Indrasena (1969), Fernando (1977), Fernando and De Silva (1984), and De Silva (1983a, 1985, 1988a). Briefly, the reservoir fishery is essentially a monospecific, gill net fishery of which the main constituent species is the exotic, Oreochromis mossambicus. Annual yield is now estimated at 27,000 t, approximating an annual production of 283 kg/ha (De Silva 1988a).

In the perennial reservoirs of Sri Lanka, stocking major Chinese and Indian carps has met with only limited success (De Silva 1988b). All the evidence gathered to date indicates that the stocking of perennial Sri Lankan reservoirs with subtropical riverine Chinese and Gangetic carp species is neither commercially viable nor scientifically justified. Similarly, the success of such practices is still to be proven for most tropical, reservoir capture fisheries in the region (Sreenivasan 1984; Chookajorn and Bhukaswan, this volume).

The general trend in the establishment and development of most reservoir fisheries in Sri Lanka has revolved around exotic cichlids and the use of gill nets of uniform mesh size (De Silva 1983a, 1988a; Amarasinghe and Pitcher 1986); this is also the case in Thailand (Bhukaswan 1985; Chookajorn and Bhukaswan, this volume). There are two reasons for this trend: first, the bottom topography and numerous obstacles such as decaying tree trunks prohibit the use of any dragging gear and, second, the most effective gear for a majority of the reservoir fish species in the region is, in fact, a passive gear such as gill nets.

New Resources

The paucity of lacustrine species and the uniformity of the fishing gear have unintentionally imposed limitations on the utilization of reservoir fish resources. The data from experimental gillnetting and commercial scale trials indicate that protein sources could be more effectively utilized through the introduction of well-managed fisheries for the exploitation of minor cyprinid resources in reservoirs.

In Sri Lanka, as elsewhere in the region, the piscine fauna has a significant number of riverine cyprinid species that do not grow above 15 cm and some species that reach only 7-10 cm in length. Of the riverine minor cyprinids, however, only about eight species have effectively colonized the vast acreage of lacustrine habitats created by man over the last 2000 to 2500 years (Table 1).

Schiemer and Hofer (1983) found that some minor cyprinid species were abundant in a reservoir that has been intensively exploited for O. mossambicus for nearly 30 years. Based on this observation, De Silva (1983a) hypothesized that these minor cyprinids could be effectively exploited without harming the commercial fisheries.

Table 1. Indigenous minor cyprinids that have been recorded in reservoirs of Sri Lanka.

Species	Comments and occurence[a]	Reference[b]
Barbus dussumieri, B. sarana	Contribute to the existing commercial fisheries of most reservoirs	1,2
B. chola	B	1,2
B. dorsalis	A	1,2,3,4
B. filamentosus	Restricted colonization (C?)	3
B. ticto	Confined to reservoirs in central and eastern Sri Lanka	5 4
Rasbora daniconius	A	3,5
Danio aequipinnatus	Not recorded in large numbers; rare in reservoirs in southern Sri Lanka	3
Amblypharyngodon melettinus	Common in most reservoirs throughout Sri Lanka	1,2,3,4

Note: There are 28 recorded minor cyprinids in Sri Lanka (Munro 1955; De Silva et al. 1981).

[a]Occurrences: A, throughout Sri Lanka; B, throughout Sri Lanka, restricted to certain reservoirs; C, throughout Sri Lanka, very restricted.

[b]1, Fernando and Indrasena (1969); 2, De Silva and Fernando (1980); 3, De Silva and Sirisena (1987); 4, Amerasinghe and Pitcher (1986); H.K.G. Sirisena and S.S. De Silva, personal observation.

This hypothesis has been tested by using multimesh gill nets in five reservoirs in southeastern Sri Lanka. Initial observations indicate that gill nets below 30 mm mesh size do not catch sizeable numbers of young or prerecruits of O. mossambicus (De Silva and Sirisena 1987). Therefore, the introduction of gill nets with mesh sizes below 30 mm is unlikely to have a detrimental effect on the O. mossambicus population and, hence, the existing commercial fishery.

According to Sirisena and De Silva (1987), catches of minor cyprinid species by weight in experimental gill-net surveys exceeded 50% in all reservoirs. Based on these surveys, the potential catch of minor cyprinids using 20- and 30-mm mesh gill nets exceeds that of O. mossambicus. This is true for the experimental surveys or the existing fishery (Table 2). Therefore, there is clear evidence that substantial minor cyprinid resources exist in Sri Lankan reservoirs (Fig. 1) and that this resource has the potential to support a viable fishery.

Table 2. The weight (kg) of minor cyprinids and *Oreochromis mossambicus* with other presently commercially exploited species caught per unit gill net (75 m x 1.8 m) of appropriate mesh size based on commercial catches (CC) and experimental gill net (EG) catches.

Reservoir	Minor cyprinids			Others[a]	
	15[b]	25[b]	30[b]	CC	EG
Muruthawela	0.30	3.80	1.04	0.15	0.70
Ridiyagama	5.76	0.23	1.75	0.38	0.49
Tissawewa	7.56	3.98	5.48	0.52	1.81
Yodawewa	10.91	0.58	2.67	0.39	1.29

Source: Sirisena and De Silva (1987).
[a]Mesh size 75 mm.
[b]Mesh size (millimetres).

Single-mesh, commercial-size gill-net surveys were carried out (Table 3). These surveys include only three of the five reservoirs in which the original survey was performed. A newly impounded reservoir, Lungamwehera, was also surveyed. The results include the catches made by commercial fishermen and by the survey team.

Discussion

The uniformity of gear has prevented the optimal utilization of the available resources in the man-made lacustrine habitats of Southeast Asia. The minor cyprinids may constitute one such available

Fig. 1. A sample catch of minor cyprinids from the multimesh gill-net experimental gear.

Table 3. Catches (kg/net) from gill-net surveys carried out with 15- and 30-mm mesh commercial nets (50 m x 1.5 m) in four Sri Lankan reservoirs.

Reservoir	No. of surveys		Minor cyprinids				*O. mossambicus*				Others			
			15 mm		30 mm		15 mm		30 mm		15 mm		30 mm	
	S[a]	F[a]	S	F	S	F	S	F	S	F	S	F	S	F
Badagiriya	2	-	1.3	-	0.95	-	0.004	-	0.006	-	0.12	-	0.09	-
Ridiyagama	2	3	2.5	1.7	0.17	0.36	-	-	-	0.02	0.04	-	0.09	0.15
Muruthawela	2	4	-	-	2.46	2.94	-	-	-	-	-	-	-	-
Lunagamwehera	2	1	4.7	4.6	0.11	-	-	-	0.004	-	0.16	0.37	0.02	0.01
Average			2.83	3.15	0.92	1.65	-	-	0.005	0.06	0.11	-	0.05	0.02

Note: In some reservoirs, fishermen were given survey nets.
[a]S, survey team; F, fishermen.

resource and this paper clearly shows the potential of exploiting this resource. As most of these species are likely to migrate upstream for breeding (De Silva 1983b; Silva and Davis 1986), however, it is necessary, at least in the initial stages, to ascertain whether the exploitation of this resource should be limited to specific times of the year.

The introduction of small-mesh gill nets on a commercial scale must be subjected to strict managerial controls. The use of these nets in areas within the sublittoral and littoral regions or adopting them as seines would undoubtedly have undesirable effects on the existing fishery. The increased exploitation of minor cyprinids must be carried out in stages under strict managerial control. The manageable size of a single piece of small-mesh netting would be about 50 m and a number of such pieces must be utilized on a commercial scale by a single boat.

In one respect, this study contradicts the hypothesis of Fernando and Holcik (1982), that it is essential to make cichlid introductions into the region to utilize the resource as a protein source. The cichlid introductions have undoubtedly paid rich dividends and will continue to do so, at least in most countries of the region (De Silva and Senaratne 1988). However, as outlined in this paper, there may be an extensive supply of indigenous species in the reservoir that could support an artisanal fishery without the introduction of exotics.

Minor cyprinids are unlikely to be utilized for direct human consumption, at least in the initial stages of a fishery. However, this resource could provide a raw-material base for a rural fish-meal industry. In view of the high density of reservoirs in Sri Lanka, such a rural, small-scale industry could be developed without much difficulty. Reservoirs could also provide other protein sources, such as carnivorous species, that are minimally exploited in most countries of the region.

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RESERVOIR BED PREPARATION IN RELATION TO FISHERIES DEVELOPMENT: AN EVALUATION

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Abstract *In Asia, the reservoir area is increasing significantly. In the planning and construction of reservoirs that are mostly built for irrigation or hydroelectric purposes, fisheries-development aspects are not being considered. There is increasing evidence that incomplete clearing of the reservoir bed is favourable for fisheries. However, most of the evidence has originated in the West. This paper evaluates the pros and cons of leaving wooded areas in reservoirs under construction for the development of fisheries and concludes that the available evidence favours retention of uncleaned areas and that more research to quantify the positive effects of this practice in the Asian region is needed.*

In almost all instances, major resrvoirs are built for irrigational, hydroelectrical, or water-supply purposes. The secondary benefits of such water bodies are rarely considered in the planning stages or in the cost-benefit analyses. It could well be that, in spite of this situation, the secondary benefits outweigh the primary benefits. For example, the annual fish yield from the Ubolaratana Reservoir in Thailand is estimated to be worth USD 1.2 million; annual hydroelectric power output is estimated at USD 1 million (Fernando 1980).

Southeast Asia now has approximately 30 x 10^5 ha of reservoirs and 35 x 10^5 ha of natural and floodplain lakes (Fernando 1982). The reservoir area is expected to increase to 200 x 10^5 ha by the year 2000. Sir Lanka has about 1.75 x 10^5 ha of man-made reservoirs (Fernando and de Silva 1984). This area is expected to rise to 2.5 x 10^5 ha by the year 2000, resulting in an approximate reservoir density on the island of 4 ha/km^2.

Unfortunately, in most instances, potential uses for these reservoirs (e.g., fisheries) are not considered during the construction or preparation of the reservoir beds or associated channels. Moreover, there appears to be a controversy and an uncertainty, mostly unwritten, regarding reservoir bed preparation in relation to fisheries development as a secondary benefit.

This paper reviews the available data on suitable methods of reservoir bed preparation aimed at establishing a reservoir fishery.

This study was prompted by one of the biggest river-diversion and associated reservoir-construction projects ever undertaken in the region: the Mahaweli Ganga (river) Diversion in Sri Lanka. In this project, all the reservoir beds, amounting to nearly 20,000 ha, were completely cleared of vegetation; in certain cases, even the grass was burned.

The Problem

From the point of view of developing a fishery, the greatest uncertainty lies in whether the area to be impounded should be cleared of its vegetation and, if so, to what extent. Other provisions to facilitate fish production must also be examined. Bhukaswan (1980) dealt with these problems and further evidence has accumulated with respect to the need for leaving a substantial proportion of the vegetation in the reservoir beds. The effect of preimpoundment clearing on reservoir ecology and fisheries in North America was recently evaluated by Ploskey (1985). This study favours the retention of some uncleared areas for fisheries development.

The extent of vegetation clearance is primarily determined by the irrigational and hydroelectrical engineering requirements of the system. In general, complete clearing is needed only in the region of the spillway and the sluices and perhaps in the dead-storage area. It must be remembered, however, that depending on the primary purpose of the reservoir, some effects could be considered as both detrimental and, from another point of view, useful.

Detrimental Effects

Impedence to Fishing

Submerged vegetation impedes fishing and limits the diversity of useful fishing gear; only drift nets, traps, and longlines can effectively be used. In most Southeast Asian reservoirs, except perhaps Indian reservoirs where fishery operations are conducted by shore seines and drag nets (Bhukaswan 1980) and those reservoir fisheries based predominantly on benthic species, the need to use bottom, dragging gear rarely arises. Southeast Asia does not contain indigenous species that could form the backbone of a lacustrine fishery.

Water Quality

It is often claimed that submerged wood causes a deterioration in water quality. Ploskey (1981), however, found little difference in water quality between wooded and cleared coves in reservoirs. Standing, submerged timber provides only a small reactive surface in comparison to its volume. This, together with the cellular characteristics (the presence of lignin, cellulose, etc.), is likely responsible for the slow decomposition of the submerged tree trunks. This slow decomposition is unlikely to have a major impact on the accumulation of potential carcinogenic precursors or other chemicals impacting the colour, odour, or taste of the water.

Eutrophication

Eutrophication is the process, either natural or artificial, by which water becomes rich in nutrients (Rohlic 1969). Eutrophication may cause changes in the faunal and floral communities and interfere with reservoir use, particularly, if the water is meant for drinking. The most apparent visible effect of eutrophication is an increase in the algal or macrophyte population, which could result in fish mortality through deoxygenation. It is now know that blooms of blue-green algae are primarily due to climatic conditions (Stepanek et al. 1963) and that such blooms often coincide with a nutritional deficiency (Pearsall 1932).

The direct effects of eutrophication on fish populations have been reported from reservoirs in the United States. Larkin and Northcote (1969) suggested that eutrophication could limit the habitat for many desirable species, thereby directly impacting foraging sites, spawning sites, and protective sites.

There is no evidence to indicate that the submerged wood releases sufficient nutrients to cause eutrophication. As pointed out, the rate of nutrient release from submerged wood is slow and, by itself, is unlikely to cause eutrophication.

Trihalomethane Precursors

Trihalomethanes are precursors to many mutagenic and carcinogenic compounds (Layher 1984). Their presence is important only for those reservoirs whose water is used for drinking. Nevertheless, bearing in mind that, in Southeast Asia, communities living around reservoirs utilize the reservoirs for domestic purposes, the water should be monitored for trihalomethane precursors.

Kraybill (1978) demonstrated that 42% of carcinogenic compounds come from natural products. The majority of these chemicals originated from allochthonous inputs from agricultural and industrial practices. In Sri Lanka, a series of reservoirs are generally found in a particular river system, one reservoir feeding the other reservoir. The reservoirs found lower down in such a series are bound to receive irrigation run-off, which invariably carries a high load of agricultural chemicals and carcinogens, possessing detrimental properties.

Beneficial Effects

Extra Riches, etc.

There is no doubt as to the importance of submerged tree trunks in providing extra niches, food resources, spawning sites, etc., to various fish species (Table 1). In certain countries, such as Sri Lanka, shelters are created by sticking large twigs known as brush piles into the reservoir bed; these remain a main mode of fishing (Senanayake 1982). Apart from the periphyton and faunal elements associated with submerged vegetation, littoral vegetation could also provide a direct food source for fish species in reservoirs (Dudgeon 1983; De Silva et al. 1984).

Table 1. The creation of new habitats, food resources, etc., in wooded areas in various reservoirs.

Reservoir	Species[a]	Observation/Function	Reference
Bull Shoals Reservoir, USA	Spotted bass	Preferred brush area for spawning	Vogele and Rainwater (1925)
	Black crappie	Vegetation crucial for spawning	Ginnelly (1971)
Smith Mountain Lake, U.K.	Largemouth bass	Highly associated with structure	Prince and Maughan (1979)
Lake Kariba, Africa	No. of species	Additional food material in submerged tree trunks	Boon (1984)
	No. of species	Submerged dead trees were associated with higher densities of chironomid larve, oligochaete worms, etc., and act as a food source for a no. of species of fish	McLachlan and McLachlan (1971)
Lewis and Clark Lake, SD, USA	Largemouth bass	Young of the year in August was related to the number of acre-days of timber inundation earlier in the year	Aggus and Elliot (1973)
Missouri reservoirs	-	Chironomid density was 11 times higher in adjacent bolt in areas	Cowell and Hudson (1967)

[a]Species of fish that are influenced by the wooded area, if known.

Influence of Birds

Aquatic predatory birds are known to remove substantial amounts of the ichthyomass in lakes and reservoirs. Vareschi (1979) estimated that the great white pelican (Pelecanus onocrotalus roseus), which roosts on a nearby salt lake, harvested 16,000-20,000 kg fish (fresh weight)/day from Lake Nakuru, Kenya. He estimated that this removal amounted to 10% of the lake's total annual phosphorous load. In Parakrama Samudra, Sri Lanka, it is estimated that the fish consumption by three species of cormorants (Phalacrocorax carbo, P. fuscicollis, and P. niger) was 696 kg/day and the nutrient export as a result of these birds could reach one-third of that lost through outflow (Winkler 1983). The final analysis of the impact of predatory birds on nutrient cycling remains controversial.

Most of the work on the role of birds in nutrient cycling has been carried out on water bodies larger than those found in Southeast Asia. In most reservoirs in Sri Lanka, for example, where the flushing rate is very high, even small changes in the nutrient export/import balance could have significant effects on productivity. Whether there are emergent tree trunks or not, predatory aquatic birds will prey on fish. It is argued, therefore, that tree trunks would provide roosts for colonies of certain species and that there would be a certain amount of nutrients cycled back into the water, thereby resulting in a reduction of the nutrient exportation from the system. Quantitative data for the above hypothesis is not yet available and admittedly will be difficult to obtain.

In Sri Lanka, it has also been postulated that the predatory role of aquatic birds is important in preventing, retarding, or stunting the growth of Oreochromis mossambicus and other cichlids (Fernando and Indrasena 1969).

Standing Stock of Ichthyomass

There is considerable evidence to indicate that reservoirs with submerged vegetation or tree trunks have a higher standing stock of ichthyomass and that, within a reservoir, the standing stock is less in those regions without tree trunks or submerged vegetation (Table 2). Table 2 clearly shows that fish production in wooded areas is higher than in nonwooded areas.

In Sri Lanka there is an in situ experiment in an ancient reservoir (Parakrama Samudra) that exemplifies this point. This reservoir has three distinct basins: the northernmost basin, known as the Thopawewa (652 ha), the middle basin, known as the Eramuduwewa (1538 ha), and the southern basin, known as the Dumbutullawewa (362 ha). The characteristics of these three basins and fishery aspects of the reservoir have been dealt with in detail by Schiemer (1983) and De Silva and Fernando (1980), respectively. The middle and southern basins of this reservoir went into disuse and were only restored in the second quarter of this century. Suffice to say that, except in the northernmost basin, the reservoir has an extensive amount of emergent trees that are in various degrees of degeneration (Fig. 1). Nevertheless, in this reservoir, which has an average annual yield of 200 kg/ha (De Silva and Fernando 1980) and provides the livelihood for nearly 2000 fishermen, fishing activities are more concentrated in the middle and southern basins (Table 3).

Table 2. Ichthyomass yields of wooded areas and cleared areas of various reservoirs.

Reservoir	Species[a]	Mean annual standing crop (kg/ha)		Reference
		Nonwooded	Wooded	
Turtle Creek Reservoir, USA	13 species (grizzard shad)	2204 (1969-1974)	542.0 (1969-1970)	Layher (1984)
Suderma Arm, Marion Reservoir	13 species (common carp)	153.9 (1974/75)	507.7 (1974/75)	Layher (1984)
Rybinsk Reservoir	All species	No quantification given; highest fish catch from submerged floodplain		See Ploskey (1981)
Bull Shoals Reservoir, USA	Predatory species	3430	127	See Ploskey (1981)
Parakrama Samudra, Sri Lanka	3 primary species (*O. mossambicus*)	Fishery least intensive	Fishery intensive	Amarasinghe and Pitcher (1986)

[a]Dominant species of the fishery is given in parentheses.

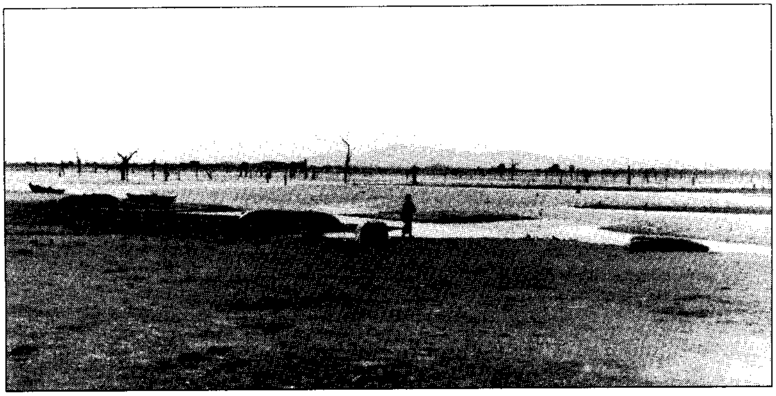

Fig. 1. Emergent trees in the middle basin of Parakrama Samudra.

Table 3. Concentration of fishing activities in the three basins of Parakrama Samudra.

Basin	Boats registered/ha	Boats operated/ha[a]
Northern	0.90	0.53
Middle	1.18	0.90
Southern	1.32	0.93

Source: Amerasinghe and Pitcher (1986).
[a]Operating at any one time.

A survey of the fishermen of Parakrama Samudra indicated that although the rate of damage to the nets is high (must be replaced once every 6-8 months) and fishing is difficult in the middle and southern basins, all of them agreed that the yield of the northern basin (cleared basin) is not sufficient. Therefore, it is apparent that even though vegetation and standing tree trunks impede fishing, fish tend to congregate in such areas and commercial fishing is viable.

Erosion and Siltation

Although erosion is retarded by the presence of forests (Hulsey 1959; Ilina and Gordevyev 1970), wooded areas may increase the rate of siltation. Submerged trees may also aid in filtering out trees, limbs, and debris drifting downstream during high water (Nelson et al. 1978). When standing timber falls over after several years, there is no threat of clogging intakes or outlets as the timber tends to remain sedentary for many years because of its waterlogged condition.

Conclusions

A quantitative evaluation of the detrimental and beneficial effects that submerged vegetation has on a reservoir fishery is difficult, if not impossible, in most instances. Furthermore, it is

There is, however, convincing evidence available to indicate that the standing stock of ichthyomass is higher in a wooded area of a reservoir. This indicates, at least indirectly, that submerged wood enhances overall fish production. As such, it would be desirable to leave some wooded areas when impounding a reservoir.

There is only limited data available indicating to what extent wood should be left intact in a reservoir bed. If one considers the Sri Lankan example, Parakrama Samudra, it would be desirable to leave approximately 50% of the forest cover of the reservoir bed; however, this aproximation has little scientific basis. Hopefully, future comparative studies on Sri Lankan reservoirs completely and partially cleared of vegetation will permit a better quantitative evaluation of this question.

This brief evaluation has not considered other provisions needed for the establishment of a reservoir fishery (e.g., fish passages and artificial spawning grounds). These aspects have been dealt with in detail by Bhukaswan (1980). The cost aspects of clearing as opposed to the value of timber have also not been considered. This is because of the immense variability in timber types and commercial values, both locally and from one country to another.

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ABSTRACT

Age and Growth of Anguilla bicolor and Anguilla nebulosa: a Case Study

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As part of a study on unexploited resources in tropical reservoirs, the occurrence and abundance of eels were investigated in five lowland reservoirs in southeastern Sri Lanka. The fishing gear used was mainly double fyke nets, but some additional catches were made using longlines (both floating and sinking). Test fishing was performed during our five visits to Sri Lanka, covering all seasons. About 470 *Anguilla bicolor* and 410 *Anguilla nebulosa* were caught. The abundance, expressed as catch per unit effort (CPUE), was the highest in Badagiriya, where about 2 eels/double fyke net per day were caught. The abundance fluctuated significantly in Badagiriya from season to season from 1 to 8 eels as CPUE. Also, the proportions of *A. bicolor* to *A. nebulosa* varied greatly from 0.3:1 to 6.3:1. The by-catch of other species was small in the fyke nets; only *Glossogobius giuvis* was caught in any significant numbers. Otoliths and the length-frequency distribution were analyzed to find the growth rates of both eel species. The results were rather inconclusive but indicate an annual growth of about 6-12 cm in eels 40-60 cm total length. To get a better esimate of the growth rates, eels of both species in Badagiriya were tagged individually with jaw tags. The maximum CPUE values found were rather high in comparison with European catches. Because the dynamics behind the fluctuations (i.e., recruitment and migrations) are still unknown, however, it is impossible to assess the potential yield of eels in Badagiriya.

DISCUSSION

The first paper presented in this session discussed the predominant fish species of the Jatiluhur Reservoir in Indonesia. In the Jatiluhur Reservoir (West Java) during the early period after inundation, the total fish production was as low as 41 t/year. Three years after inundation, production increased to 310 t/year. In subsequent years, production first decreased, but, in 1968, started to increase again, reaching 453 t/year in 1986. This increase was most probably due to an increase in fishing pressure.

Oreochromis niloticus has been present in the Jatiluhur Reservoir since 1972, but it constitutes only 0.2% of the total fish catch. Its low density in this reservoir has probably been due to the relatively small spawning area available in the reservoir. This species needs a shallow littoral area for spawning. The older tilapia are also predominantly present in the shallow areas of the reservoir, which is only a small part of the total reservoir area. Because of this low density, any effect on the indigenous fish in the reservoir has been negligible.

The second presentation dealt with growth overfishing in Sri Lankan reservoirs. U.S. Amarasinghe observed that for *Oreochromis mossambicus* in five Sri Lankan reservoirs there was a negative correlation between the body condition and the density of small (20 cm in length) juveniles. This phenomenon can best be explained by the fact that the fishing pressure in the five reservoirs studied has been varying. Generally, the higher the fishing pressure, the earlier the fish matures, and probably more energy was allocated to gonad production than to somatic production. This results in a poor body condition as well as probably stunted growth. More research is necessary to explain fully this observation.

The presentation by Dr De Silva discussed reservoir bed preparation in relation to reservoir fisheries. When constructing new reservoirs, up to 50% of the reservoir bed could be left with its vegetation to provide niches and spawning places for the fish. Vegetation is especially important in the shallow littoral areas. In China, however, the situation is different as the most important food fish, the Chinese carp, does not spawn in the reservoir itself, but is introduced as fingerlings every year. Under these circumstances, more of the vegetation may be cleared without any negative effect on the fish stock, as this would facilitate easy harvesting by sophisticated methods as usually done in China.

General Discussion

In general, O. niloticus is probably one of the best cichlid species used in aquaculture. Some specific strains of O. mossambicus (e.g., some south African strains) are also very good. When choosing fish species for introduction, it should be considered that different strains of the same species may show large variations in adaptability to environmental conditions and in production characteristics. It should also be realized that reservoirs are much more complex systems than aquaculture systems. Consequently, species or strains of species that perform well in aquaculture systems are not necessarily the best choice for introduction into reservoirs.

Session IV

Management Aspects

POSTIMPOUNDMENT CHANGES AND EFFECTS OF CONFLICTING USES ON THE FISHERIES OF TUNGABHADRA RESERVOIR, INDIA

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Abstract *The Tungabhadra Reservoir (37,814 ha) was impounded across the Tungabhadra River near Hospet in Karnataka, India, in June 1953. The highly productive reservoir offers good possibilities for the development of the fishery and the enhancement of the annual fish production from the present average of 135 kg/ha to above 250 kg/ha. The almost complete withdrawal of water for priority needs such as irrigation, power generation, flood control, and lift irrigation schemes together with poor inflow and heavy siltation of the reservoir results in a depletion in the water volume from* $3,275 \times 10^6$ m^3 *at full supply level (FSL) to less than* 28×10^6 m^3 *and a reduction in the water area from 37,814 ha to less than 2,000 ha from November to April. The intensive fishing with fine-meshed, large, shore seines and gill nets from November to June, especially under low-water conditions in the summer, has reduced the stock and adversely affected the conservation and development measures that have been undertaken. This paper discusses the postimpoundment changes of the reservoir and studies in detail the various conflicting uses of the reservoir and their impact on the fisheries.*

Most of the existing projects in the Tungabhadra River valley are designed and have been constructed primarily for irrigation, power generation, flood control, and domestic and industrial water supply. Fisheries has not been a priority area during the planning and construction stages, and only incidental importance has been given to fisheries after impoundment. Therefore, it has been impossible to achieve optimum, sustained levels of fishery development and production, even though the fishery technologies and resources are available.

The Tungabhadra Reservoir, with a water area of 37,814 ha at full supply level (FSL) and a highly productive nature (Govind 1963; David et al. 1969) offers wide possibilities for the development of fisheries and the enhancement of annual fish production from the present level of 135 kg/ha to over 250 kg/ha. However, the almost complete withdrawal of available water for priority needs as well as the poor inflow and heavy siltation of the reservoir leaves little water in the summer for the sustenance of developmental efforts and conservation of the stock.

Study Area

The Tungabhadra project is one of the major multipurpose projects in southern India. The Tungabhadra Dam (length, 2.4 km) has a central spillway across the main river and is an earthern composit dam. The maximum water spread near the dam is 15.3 km and the fetch is 85.34 km. The original storage capacity was 3751 x 10^6 m^3. The maximum flood discharge of 16,990 cumecs is designed to be discharged through 33 vents having crest gates of 18.28 x 6.09 m with a crest level at reservoir level of 491.64 m and a full reservoir level of 497.74 m (Table 1).

Postimpoundment Changes

The lacustrine unit of the Central Inland Fisheries Research Institute conducted investigations on the limnology, fisheries biology, and fish exploitation of the Tungabhadra Reservoir after impoundment during 1964 and 1965 (David et al. 1966). Many changes have been observed (Table 2).

Faunal Fishes

The fish fauna of the reservoir is known to be "rough" or "course," consisting mainly of residual and acclimatized catfishes from the river, a rich forage fish population, and minor carps. During 1958/59, 300,000 Gangetic carp seeds were procured from Calcutta and a first stocking was conducted. Until the completion of the fish seed production farm in 1963/64, imported seed from Calcutta was reared and stocked. Later, seed produced in the fish farm 40-60 mm), mostly common carp and mrigal during the initial years, was stocked. This stocking, however, did not result in the establishment of a significant fishery. The poor density of seed stocking and larger catfish population may be the reason for the poor representation of Gangetic carps in the commercial catches until a decade after the commencement of the stocking. Of the genus *Mystus*,

Table 2. Changes in fish populations in the Tungabhadra Reservoir

Introduced	Disappeared	Dwindled	Now dominant
C. catla	*P. dobsoni*	*P. kolus*	*Oxygaster* sp.
L. rohita	*P. pulchellus*	*P. calbasu*	*Chela* sp.
C. mrigala	*Tor* sp.	*P. sarana*	*Osteobroma* sp.
	L. fimbriatus	*C. reba*	*Ambasis* sp.
	L. nukta	*P. taakree*	*Puntius* sp.
	M. aor	*C. marulius*	*Aspidoparia* sp.
	B. hagarius	*C. striatus*	*Wallago attu*
	R. pavimentata	*N. notopterus*	*M. seenghala*
	S. childrenii	*M. punctatus*	*M. cavasius*
			O. bimaculatus
			M. armatus
			C. catla
			L. rohita

Table 1. Hydraulic particulars of the Tungabhadra Reservoir.

Parameter	1977/78	1978/79	1979/80	1980/81	1981/82	1982/83	1983/84	1984/85	1985/86	1986/87
Inflow (x 10^6 m^3)	7798.6	15822.6	8249.8	15661.9	10269.0	10462.4	8955.2	8585.2	6152.2	6911.2
Total outflow (x 10^6 m^3)	7570.3	15982.4	8176.1	16016.8	10412.0	10471.0	8897.5	8694.4	6169.7	NA[a]
Evaporation (x 10^6 m^3)	475.8	442.8	444.7	416.6	363.1	341.6	351.8	352.4	320.0	NA[a]
Reservoir level (m)										
Maximum	497.7	497.7	497.7	497.7	497.7	497.7	497.7	497.7	497.7	497.7
Minimum	485.8	486.0	485.6	478.2	477.9	476.4	480.5	477.2	476.0	476.5
Capacity (x 10^6 m^3)										
Maximum	3430.6	3430.6	3430.6	3430.6	3430.6	3430.6	3430.6	3430.6	3430.6	3430.6
Minimum	490.0	531.6	476.6	56.0	50.9	18.2	107.5	29.1	13.8	19.1
Reservoir area (ha)	12481.1	12703.1	12291.4	4205.6	3978.9	1133.5	3858.0	1503.1	1037.7	1209.6
Rainfall (mm)	645	748	537	527	662	616	651	576	584	540

[a]NA, not available.

however, Mystus punctatus (Jerdon) is the largest growing species in India. Fish weighing 25-35 kg are commonly caught and fish weighing up to 120 kg have also been caught.

Commercial Fishery

Fish landings were 15-11 t in 1958 and 1959 and, with the introduction of a licencing system, the catch records showed an improvement of up to 24 t between 1960 and 1962. A sudden increase in the estimated production to 69 t in 1963 was due to an increased effort by many fishermen introducing stray alivinets (small-meshed, large drag nets). Since 1964, the fish composition was dominated by carps up to 58.5 to 75.1%, of which Puntius kolus accounted for 22.7 to 33.3% and catfish catches ranged from 22 to 47%. With the introduction of alivinets in 1964, fish catches have increased and fish composition has changed considerably. The carp population fell to 30.5% in 1964 and, at the same time, the catfish population increased to 67.9%. Puntius kolus decreased to only 9.48% of the total weight of the fish catch and, among catfishes, Mystus seenghala and M. aor increased from 18.2 to 36.5% and from 7.2 to 11.1%, respectively.

From 200 t in 1963/64, the fish production increased to a high of 4200 t in 1981/82. This was mainly due to increased fishing efforts as more shore sienes were added yearly until 1980. After 1980, when the water level dropped below 478 m, there was a vast reduction in the volume and area of water. By 1986/87, the water levels had dropped to 476.6 m, with 28 x 10^6 m^3 of water (3275 x 10^6 m^3 at FSL).

As seen from the present fish-production statistics and species composition, over 90% of total production is trash fish harvested with alivinets; trash fish are sun dried and marketed dry. Only 10-12% of the total catch from the gill nets and alivinets is marketed fresh. The size of the economic catfish and carps have gradually reduced and, at present, mostly 0+ and 1+ juveniles are harvested.

Multiple Uses

Irrigation

The primary purpose of the Tungabhadra Reservoir project is irrigation. The reservoir irrigates about 512,000 ha, of which 350,000 ha is in Karnataka and 160,000 ha is in Andhra Pradesh. The Tungabhadra Board regulates the water available in the Tungabhadra Reservoir, 6512.8 x 10^6 m^3 is made available for irrigation through different canals in a "water year" (1 June to 31 May) as per the interstate agreement.

Beginning in 1967, 33 lift irrigation schemes have been sanctioned and commissioned (18 on the right bank and 15 on the left bank), with a total combined irrigation discharge of 517.47 cusecs and a total contemplated anicut of 9518.41 ha on both banks. Water is lifed and discharged for irrigation when the water level in the reservoir rises above 489.33 m in July and continues until the water level drops below 489.33 m in February or March. Commercial crops such as groundnut, sunflower, maize, cotton and jowar are mostly grown and it is estimated that 75-85 x 10^6 m^3 of water is utilized for lift irrigation schemes.

Power Generation

The Tungabhadra project also generates hydroelectric power. There are three power-generating stations with an installed capacity of 99 MW. Normally, during the rainy season, full generation is maintained. During other periods, power generation is limited depending upon the water level of the reservoir and the requirements of the irrigation branch.

Domestic and Industrial Needs

The project supplies drinking water year-round to the camp areas at Tungabhadra Dam, Munirabad and Hospet, Sindhanur, Bellary, Raichur, Manvi, and Gadag, and to several small municipalities and villages. There are also several large industries located near the Tungabhadra Dam that are highly water consumptive and draw water from the reservoir. There are several small- and medium-size industries around Hospet that depend on the reservoir for their industrial water needs.

Siltation

The useful life of a reservoir depends on the rate of sedimentation and the rate of sedimentation, in turn, depends on the rate of sediment input by the river or rivers entering the reservoir (De Silva 1985). Large inputs of silt have drastically reduced the volume of water available for fish production (Baluyut 1985). The capacity of the reservoir reduced by 13.5% in its first decade of existence (David et al. 1969). Several silty islands and bars have been formed within the reservoir bed and, in places, the silt is 3.5-4.5 m deep. The characters of the reservoir bed have also been modified by the deposited silt, which is mainly clay.

The capacity of the reservoir of 1985 at FSL 497.74 m was 3166.74 x 10^6 m^3 and the quantity of silt deposited from 1953 to 1985 was 586.22 x 10^6 m^3 (Table 2). The consequent loss in dead storage is 100% and the loss in live storage is 14.8%; the overall loss in impounding capacity compared with 1953 is 15.58%.

Besides a loss of storage capacity sedimentation has many other environmental effects that can severely damage the fish population and its habitat. Food supply, growth, and spawning are particularly affected (Jhingran 1974; Srinivasan 1986).

Water Level Fluctuation

Apart from rainfall, the water supply to the reservoir is dependent on many other factors. Beginning in November, inflow is reduced and the water level decreases rapidly. By April-May, the water level may drop to around 475 m (Fig. 1) and the water spread will drop from 37,814 ha at FSL to < 2,000 ha. Thus, most of the rich sediment deposited in the reservoir is exposed and widespread drawdown agriculture is practiced by the villagers without fertilizer input.

Drawdown also exposes submerged plants and bottom animals to dessiccation and damage by wave action, reducing the food supply and refuges of many fish (Srinivasan 1986). In fact, water level is the

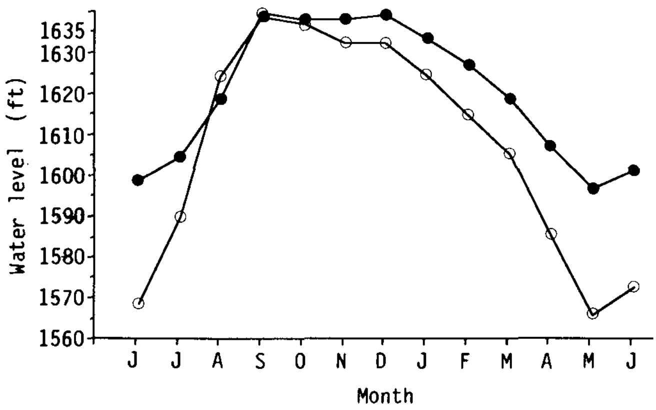

Fig. 1. Water-level fluctuations for 1979/80 (●) and 1986/87 (○) in the Tungabhadra Reservoir (1 ft = 0.305 m).

main controlling factor of aquatic vegetation, which is the main food of herbivorous fish such as Puntius dobsoni, Puntius pulchelus, and Puntius sarana (David et al. 1966). Walburg (1976) observed that spawning conditions for most species have deteriorated over the years because of shoreline siltation and water level fluctuations during the spawning period. In the Tungabhadra Reservoir, wide fluctuations in water levels and severe drawdown with heavy shoreline siltation and large-scale operation of shore seines in the shallow marginal areas are responsible for the gradual dissappearance of many fish species, particularly herbivorous fish.

Industrial Pollution

There are several major industries on the Tungabhadra River system causing severe industrial pollution. Many are located on the Bhadra River in the industrial town of Bhadravathi in Shimoga District before its confluence with the Tunga River (David 1956). Joseph (personal communication) has found zinc levels from 80 to 120 mg/g dry weight in Puntius kolus from the Tungabhadra River near Harihar. Chromium was also detected in both the river water and the fish. Regular monitoring of the Tungabhadra River near Harihar by the Karnataka Pollution Board in 1984 indicated high biological and chemical oxygen demands and high levels of sulphate, zinc, and chromium. The water was dark brown. The high biological oxygen demand often resulted in a reduction in the dissolved oxygen content. In fact, on several occasions, a mass mortality of fish up to 30-40 kg was reported downstream, a result of the depletion of dissolved oxygen. Studies conducted in the Tungabhadra River near Harihar in 1984 revealed that water quality had deteriorated from the point of view of drinking, agriculture, and fisheries.

Fishing Pressure and Overexploitation

The well-documented analysis of Nampong Reservoir shows constraints to the fish stocks being imposed by the fisheries itself. Lack of fishery regulations have led to changes in the character of fish stocks and to their overexploitation (Petr 1985). Bhukaswan (1980) states that in Southeast Asia and the Indian subcontinent, public fishing is an important factor causing changes in the fish species composition of the reservoirs. Gill net fishing and intensive capture of predatory fishes using hooks and longlines with live bait in the initial years of an impoundment have been found to encourage the build up of dense populations of small fish.

Soon after impoundment in 1953, the Tungabhadra Reservoir was rich in natural fish (catfish and minor carp). Gill nets and longlines with hooks and live bait were extensively used to capture these fish. The alivinets, which were introduced in 1964 to capture rich forage fish and catfish, have gradually increased in numbers and size because of the demand for dry fish and because of the infrastructural facilities available for finance, transport, and marketing. The present alivinets are 200-300 m long. The number of nets have increased from 50 in 1980/81 to 83 in 1986/87. They are operated throughout the reservoir from November to June. The mesh size of the alivinets varies from 8 to 12 mm and large quantities of forge fish, weed fish, juvenile carps, catfish, and other fish are harvested from the shallow marginal areas. As the water depletes during the summer, all the fish become concentrated in the foreshore waters where alivinets and gill nets are used on a large scale (Table 3).

The sharp decline in water levels in the reservoir (Table 3) reduces the fishing season and leads to concentrated fishing in the summer, resulting in a total exploitation of the fishery. The average size of the carp and catfish harvested drops below the marketable size and the catch per unit effort is reduced. The fishery has clearly changed from a predominately large-size catfish and carp fishery to a predominately small-sized herbivorous forage fish and weedfish fishery. These small fish constitute more that 80% of the catch and are sun dried and marketed dry. Because the water available in the reservoir is committed to the priority objective of irrigation according to the interstate agreement, it is impossible to provide the minimum conservation to safeguard the stock during the lean season. Therefore, a new fishery strategy must be developed.

Table 3. Number of licences issued and fish production in the Tungabhadra Reservoir during the last 7 years.

Year	No. of licences issued: Gill nets	Long-lines	Alivinets	Total	Fish production (t)	Alivinet contribution to total fish production (%)	Fish production at 60% FRS[a] (kg/ha)
1980/81	83	0	53	136	3529	92.17	155.54
1981/82	89	21	62	172	4200	89.76	185.12
1982/83	79	1	72	152	3301	83.50	145.50
1983/84	87	14	66	167	2490	92.60	109.75
1984/85	96	21	66	183	3255	90.90	143.50
1985/86	120	40	68	229	2752	89.82	121.30
1986/87	97	24	83	204	2068	88.36	91.18

The biological effects of heavy drawdown have been dealt with by David et al. (1966), Walburg (1976), and Sreenivasan (1986). In the Tungabhadra Reservoir, wide fluctuations in water levels and severe drawdown with heavy shoreline siltation and large-scale operation of shore seines in the shallow, marginal areas are possibly responsible for the gradual disappearance of many fish species. The above effects are particularly detrimental to herbivorous species.

It is proposed that the reservoir be stocked with large-sized fingerlings (at least 30-50 g) of fast-growing major carps (i.e., catla, ruhu, and silver carp). This stocking should be done in July, after the completion of the shore-seine fishing season when the fresh water starts building up in the reservoir. This will enable the young carps to escape the alivinets in low-water conditions and grow well in the abundantly rich flood waters of the reservoir until December; they can move into deeper water by the time the operation of the alivinets is intensified and attain a marketable size of 1.5-2.5 kg by the following summer. For this purpose, large-scale pen-culture and cage-culture operations have been initiated for raising spawn to early fingerings in pens, for rearing early fingerlings to large fingerlings in cages, and to maintain the large fingerlings in cages until the end fo the fishing season. Furthermore, fish-seed rearing is planned for the reservoir-connected tanks. These tanks separate from the reservoir at water level of 491 m in January and retain water perennially until fresh water builds up and submerges the tanks in July.

Conclusions

There is an urgent need for a central coordinating authority with experts from a variety of fields (i.e., agriculture specialists, ecologists, fisheries experts, biologists, sociologists, public health workers, economists, etc.) to ensure that all possible related impacts of the river valley projects are carefully assessed and evaluated from the planning and design stage to ensure integrated management of the project and optimal production from all sectors. There is also an urgent need for a minimum conservation pool of about 10% of the volume at FSL for the conservation of fish stocks and the promotion of developmental efforts. Sluices for the withdrawal of water for irrigation, power, etc., should be provided above the minimum fisheries conservation pools so that the minimum water is not used for other purposes in the lean seasons.

Strict enforcement of the fishery regulations during lean seasons is essential. This would reduce the extreme fishing pressure, which is causing reduced fish yields and change in species composition in favour of slow-growing, undesirable species. The effective area and volume of water available for any water body, which varies according to the uses of the water and the inflows at different times of the year, must be assessed. A strategy to obtain optimum fish production within these limitations must be developed.

Acknowledgments

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AIMS AND STRATEGIES OF FISHERIES MANAGEMENT FOR THE TEHRI DAM RESERVOIR IN THE GARHWAL HIMALAYA, INDIA

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Abstract *A number of large man-made reservoirs have come into existence or are now being constructed in the Indian Himalaya, especially during the last 20 years. This is because of the initiation of various multipurpose river valley projects and has added considerably to the existing potential for the development of India's fishery resource. This paper discusses the aims and strategies of the fisheries management program for the Tehri Dam Reservoir. The basic aim of this program is to meet the ever-increasing demand for low-priced animal protein to feed the region's human population, which is suffering from malnutrition. Strategies for the management of the fish habitat, the fish stock, and the rehabilitation of the fishing community are suggested. To ensure a high, sustainable fish yield from the Tehri Dam Reservoir, some conservation measures are also recommended.*

India has a vast potential for reservoir fisheries development. Reservoir fisheries in India occupies 2 x 10^6 ha and is likely to reach 5 x 10^6 ha before the turn of the century. Many large man-made reservoirs have been constructed or are being constructed in the Himalayan region of India, especially in the last 20 years as a result of the initiation of many multipurpose river valley projects. In the Garhwal region of Uttar Pradesh, there are 23 constructed or proposed dams. The Tehri Dam, Asia's highest, is now under contruction. Its completion will result in the formation of a huge reservoir that will be available for fishery propagation and management.

The Tehri Dam Reservoir will be formed after damming the parent streams of the Ganges (Bhagirathi and Bhilangana) about 1.5 km downstream of Tehri (24.4° N, 78.5° E) (Fig. 1). The Bhagirathi and Bhilangana, like other Himalayan rivers, have steep banks and are in a narrow valley. The river bed is 594 m above mean sea level and the expected deepest foundation is 579 m above mean sea level. Morphometric data for the Tehri Dam Reservoir are listed in Table 1.

Geology of Reservoir Area

Geological factors can constrain reservoir development. Therefore, geological studies of the area are necessary when planning the infrastructure of the reservoir; production can be improved

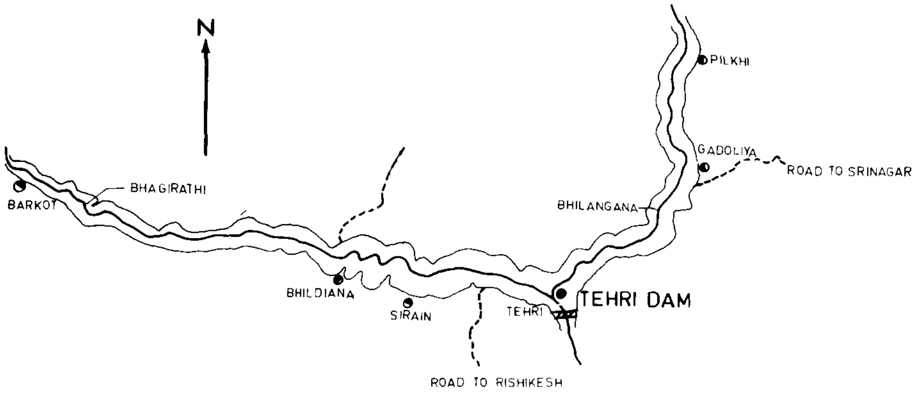

Fig. 1. Layout of Tehri Dam Reservoir.

without seriously disturbing the ecological system. The Tehri Dam Reservoir is located in the central Himalayas, which is of recent origin. The rock formation encompassing the reservoir area belongs to the phyllites of the Chandpur series (Tehri formation). In general, the rocks are alternately banded with argilaceous and arenaceous material. The foliation of phyllites generally strike in N 55° W - S 55° E to N 80° W - S 80° E with dips of 35-55° in the S 10° W to S 40° W direction (downstream).

Hydrology of Reservoir Area

Bharigathi and Bhilangana are snow-fed rivers originating in the Himalayan glaciers Gangotri (Gomukh) and Khatling. Hydrological data for the Tehri Dam Reservoir are listed in Table 1.

Preimpoundment Limnological Profile

To determine fisheries management strategies for the Tehri Dam Reservoir, a detailed limnological knowledge of the area is imperative. Preimpoundment limnological studies on Bhagirathi and Bhilangana have been made by Sharma (1984a) and Sharma and Konswal (1986). The results of these studies are presented in Tables 2 and 3, respectively.

Preimpoundment Fish Resource

Detailed surveys of the fish fauna of both Bhagirathi and Bhilangana have been made by Sharma (1983) and Konswal (1986). Bhagirathi contains 23 species belonging to 11 genera and 4 families, and Bhilangana contains 14 species belonging to 9 genera and 3 families. In addition to a survey ot the preimpoundment ichthyofauna, a survey of the main fisheries has been made (Sharma 1986). Indian Hill trout (snow trout) and mahseer (*Tor tor* Hamilton and *Tor putitora* Hamilton) were found to be the main fish of the preimpoundment area.

Table 1. Morphometric and hydrological data for the Tehri Dam Reservoir.

Morphometric data[a]		Hydrological data	
Parameter	Value	Parameter	Value
Max. dam height (m)	260.5	Annual precipitation (cm)	101.6-263.0
FSL (m)	830	Rivers' discharge (cumec)[b]	
		Winter	60
HFL (m)	835	Normal monsoon flood	900
		Max. flood	7800
Reservoir area at FSL (km^2)	42	At dam site	15540
Extent of reservoir (km)		Annual runoff (m^3)	
Up Bhilangana	25	Max.	11.2×10^9
Up Bhagirathi	44	Min.	5.5×10^9
		Mean	8.2×10^9
GSC at FSL (m^3)			
Live storage	2.62×10^9		
Dead storage	0.92×10^9		
Total	3.54×10^9		

[a] FSL, full supply level; HFL, highest flood level; GSC, gross storage capacity.
[b] Cubic metres per second past a given point.

Table 2. Preimpoundment (1979) characteristics of Bhagirathi.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Air temp. (°C)	16.6	19.0	26.3	27.8	34.6	36.3	32.6	31.3	27.8	26.4	21.3	16.0
Water temp. (°C)	13.0	13.6	16.9	19.8	18.8	18.8	15.4	17.8	19.0	17.8	15.3	12.0
Turbidity (%)	12.0	21.0	17.0	83.5	36.6	74.5	95.6	90.5	72.5	31.6	12.0	7.0
Water current (m/s)	0.438	0.340	0.355	0.756	1.057	1.970	3.331	3.602	2.056	1.314	0.938	0.841
pH	7.20	8.13	8.00	8.25	8.40	9.10	9.0	8.55	7.88	8.30	8.13	7.63
HMD[a] (m)	1.346	1.038	1.063	3.143	3.080	4.925	6.502	6.207	5.040	3.936	1.765	1.563
Dissolved O (ppm)	17.8	14.5	11.2	9.8	9.6	9.4	9.2	8.9	12.5	13.8	15.2	17.5
Free CO_2 (ppm)	4.00	4.63	5.38	6.38	4.20	3.13	3.90	4.75	5.63	5.10	4.50	4.30
Plankton (units/L)	1025	720	270	185	135	45	36	27	72	140	520	810
Benthos (units/m^2)	695	1012	837	866	290	60	33	33	107	278	346	554

Source: Sharma (1984a).
[a]HMD, hydro-median depth.

Table 3. Preimpoundment (1983) characteristics of Bhilangana.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Air temp. (°C)	13.2	14.7	21.3	19.2	27.1	29.7	30.2	34.0	33.6	28.0	22.2	14.2
Water temp. (°C)	10.1	12.7	14.1	16.2	21.4	19.2	19.4	19.1	19.0	18.2	14.1	13.2
Turbidity (%)	6.3	10.1	16.1	18.4	22.0	32.2	64.2	42.2	28.6	22.4	16.6	9.5
Water current (m/s)	0.212	0.229	0.325	0.252	0.516	0.845	1.480	1.398	1.132	0.391	0.212	0.188
pH	7.21	7.40	7.66	7.52	7.71	8.21	8.37	8.48	7.81	8.11	7.90	7.62
HMD[a] (m)	5.320	5.426	6.950	7.206	6.521	8.420	8.196	8.462	7.026	6.320	4.210	5.921
Dissolved O (ppm)	14.61	14.32	9.63	9.01	8.42	8.24	8.05	8.41	9.12	10.43	10.84	12.65
Free CO_2 (ppm)	0.32	0.41	0.92	1.21	3.56	2.12	1.82	1.21	1.57	2.02	1.42	0.53
Bicarbonates (ppm)	28.2	36.0	36.9	54.0	65.0	58.1	22.0	18.2	24.0	35.1	26.2	38.5
Carbonates (ppm)	-	-	-	-	-	-	-	-	-	-	-	-
Alkalinity (ppm)	28.2	36.0	36.9	54.0	65.0	58.1	22.0	18.2	24.0	35.1	26.2	38.5
Plankton (units/L)	27	21	16	20	12	7	3	4	10	8	13	18
Benthos (units/m^2)	609	787	696	409	263	95	59	59	87	212	371	549

Source: Sharma and Konswal (1986).
[a]HMD, hydro-median depth.

Fisheries Management Strategies

Fisheries management involves the manipulation of living aquatic resources, of the environment in which they live, and of the associated human communities (Welcomme 1985). Several management strategies for reservoir fisheries have been practiced with different degrees of success.

Management of Fish Environment

Fish production in the Tehri Dam Reservoir is secondary to hydroelectric power generation, irrigation, navigation, and tourism. Therefore, the existing environment is likely unsuitable for fish production. Problems that may arise are associated with unfavourable physicochemical conditions of the water, the feeding areas, migration, spawning grounds, excessive growth of aquatic weeds, and changes in fish species composition. Manipulation of the impounded area with respect to these factors is necessary to prevent population depletion and trophic depression.

Clearing and Leveling

In area to be affected by the dam, the town of Tehri will be submerged, 23 villages will be fully submerged, and 72 villages will be partially submerged. Therefore, the area must be leveled and cleared to make it suitable for the fish. The clearance of vegetation, which varies from dry subtropical to temperate shrubby, including a few exotics, should be selective and decided on the basis of feeding preferences, the proposed mode of fishing, and the fishing effort in the reservoir.

Fish Ladders

It has been well established that economically important species of the dam's area such as T. tor, T. putitora (Sharma 1984b), Labeo dero Hamilton (Sharma 1984c), and Glyptothorax pectinopterus McClelland (Sharma 1984d) are migratory, and any interruption in their movement would seriously affect the fisheries of the reservoir. Therefore, fish ladders will be established to facilitate upstream and downstream movement of the fish across the dam. For the successful operation of fish ladders (fish passes), fish locks should be included in the dam design. Fish locks are generally more effective than other fish passes and have been successful throughout the USSR (Jhingran 1965).

Improvement of Spawning Grounds

In most of the reservoirs of India, spawning-ground availability is the main limiting factor to the fish population. Parts of initially favourable spawning areas may become covered by sediments or made unsuitable by frequent water level fluctuations. Thus, in the Tehri Dam Reservoir, improvement of existing spawning grounds and the development of new ones is necessary for the successful propagation of indigenous and introduced species.

Downstream Management

The changes in water discharge and water quality below the dam will adversely affect the feeding and spawning grounds. This situation can be improved if the water released from the Tehri Dam Reservoir is adjusted by manipulating the downstream habitat to match the normal hydrological cycle.

Control of Eutrophication

There is strong evidence that, in time, reservoirs develop an excessive growth of aquatic weeds. This adversely affects fish development. To cope with this problem, herbivorous fish such as S. richardsonii, Garra gotyla gotyla (Gray), Crossocheilus latius (Hamilton), and a few exotic species such as grass carp (Ctenopharyngodon idella (Valenciennes)) and silver carp (Hypoththalmichthys molitrix (Valenciennes)) can be introduced.

Management of Fish Stock

To ensure maximum production at the Tehri Dam Reservoir, the fish stock must be properly managed. The following eight points should be considered when devising management strategies for the fish stock.

- The species to be introduced should be fast growing, able to breed in confinement, and have a feeding habit suitable to the food available in the reservoir. Sharma and Bhatt (1986) have developed nine food chain models for the Tehri Dam Reservoir. Their models 7, 8, and 9 would be most appropriate for stocking because the species involved occupy all three niches of the reservoir: peripheral bottom, column, and surface.

- Some highly productive exotic species could be stocked to utilize any untapped niches in the reservoir.

- Production of the fish stock could be enhanced by enriching the food reserves at different trophic levels (Bhukaswan and Pholprasith 1977; Fernando 1977; Jhingran and Tripathi 1977). This could be achieved at the Tehri Dam Reservoir by acclimatizing and transferring choice feed organisms into the reservoir.

- For effective stocking, fish hatcheries should be established near the reservoir to facilitate easy transport of the raised fingerlings.

- Sport fish (Tor spp. and Schizothorax spp.) could be introduced to attract anglers and promote tourism.

- In the Tehri Dam Reservoir, the water level should be in accordance with the requirements of the fish population.

- Using selected species, trials with floating cage culture should be undertaken. Cage culture with supplementary feeding would be advantageous because the upper layer of the impoundment will be rich in plankton, will have an adequate supply of dissolved oxygen and a high pH, and will be slightly warmer than the rest of the water column.

- To prevent fish diseases, the reservoir should be stocked with parasite-free fish and strict disease control should be practiced.

Rehabilitation of Fishing Community

The submergence of Tehri and surrounding villages as a result of the Tehri Dam will necessitate the rehabilitation of about 20,000 people, including many fishermen. The government should relocate the trained fishermen and other local inhabitants such that the collection and disposal of the catch is not a problem. The fishermen should be trained for deep-water fishing and a cooperative society of fishermen should be established to ensure proper marketing of the fish.

Conservation of Fisheries

To ensure a high and sustained yield of fish from the Tehri Dam Reservoir, strict conservation measures should be practiced. Overexploitation of the fish stock would adversely affect the growth rate and reproductive capacity of the fish population (Nikolskii 1969). The following three main conservation measures may be implemented.

Closed Season, Closed Area

In the Tehri Dam Reservoir, fishing should be prohibited from April to August, which is the spawning season of most of the stocked species (Sharma 1984b,c,d). If fishing is allowed at this time, spawning and the growth of fry and fingerlings are disrupted (Nikolskii 1979). Fishing should be prohibited in spawning areas and feeding grounds, where mature fish and fingerlings congregate.

Size Limitation of Mesh, Fish, and Catch

On the basis of preimpoundment studies on the spawning ecology and breeding biology of the fish (e.g., *T. tor*, *T. putitora*, *L. dero*, *G. pectinopterus*) of Bhagirathi and Bhilangana (Sharma 1984b,c,d), it is recommended that catching fish below 250 mm total length using a mesh size less than 30 mm be prohibited. A fixed catch limit should also be imposed.

Fishing Methods and Public Education

Destrucive fishing methods such as dynamiting, poisoning, and electric shock, which are freely practiced in the preimpoundment areas, must be strictly banned. A public education program should be initiated.

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RESERVOIR FISHERIES MANAGEMENT IN THAILAND

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Abstract *The development of reservoir fisheries in Thailand is well established at both the artisanal and commercial levels. Fish production fluctuates from year to year and varies between reservoirs. High fish yields occur in Thai reservoirs following high-water years. Emphasis, therefore, has been placed on minimizing water-level fluctuation to maintain optimum productivity. Several management techniques have been implemented to adjust yield and maintain a high production level. Different degrees of success have been achieved and further investigations and evaluation are required.*

The development of reservoir fisheries in Thailand began in the early 1960's when the first multipurpose reservoir was established. There are now 20 multipurposes reservoirs in Thailand. Most of them are shallow (11 reservoirs have a mean depth < 10 m) and productive. Ecological changes within an impoundment are favourable for the growth and production of fish, particularly limnophilic species, and experience has shown that fish production in a reservoir is greater than that obtained under riverine conditions (Sidthimunka 1972). However, fish production in most reservoirs fluctuates annually and usually peaks a few years after impoundment. This fluctuation in production is correlated to environmental changes, particularly water-level fluctuation, and the success of fishery management programs (Bhukaswan and Pholprasith 1977). The current average annual fish production from multipurpose reservoirs is estimated at 13,400 t.

Management Techniques in Thailand

In general, fish are harvested from Thai reservoirs for consumption with little or no regard to variety or size. Therefore, any management approach that increases fish production or promotes fish conservation is desirable. Several managerial techniques have been implemented by the Thai Department of Fisheries to adjust yield and maintain production near its optimum level. These activities include fish stocking, control of aquatic vegetation, regulation of fishing gear, restriction of fishing season and areas, and prohibition of destructive fishing methods.

Fish Stocking

Several fish species were stocked in reservoirs to increase production, to control aquatic weeds, and for conservation purposes. To increase food-fish production and utilize all levels in the food chain of the reservoir, intensive stocking is done during impoundment (Bhukaswan and Pholprasith 1977). Fish species commonly stocked in Thai reservoirs include Puntius gonionotus, Oreochromis niloticus, Labeo rohita, Cyprinus carpio, Probarbus jullieni, Pangasius sutchi, Ctenopharyngodon idella, Hypophthalmichthys molitrix, Aristichthys nobilis, Pangasianodon gigas, and Macrobrachium rosenbergii. The total number of fish stocked is small in comparison to the surface area of reservoirs; therefore, the stocked fish still make only a limited contribution to the commercial catch, in spite of the good growth rate of some of these species.

Control of Aquatic Vegetation

Old reservoirs are usually covered with an excessive growth of aquatic plants, causing serious problems in reservoir management. The floating variety of aquatic plant, e.g., Eichhornia crassipes and Pistia stratiotes, is the most undesirable because it blocks the navigation route and interferes with fishing activities. In addition, floating plants cause a substantial loss of water from the reservoir through transpiration. This type of vegetation is partially removed from the reservoirs during the rainy season, when the floodwater carries the plants over the spillway. The growth of submerged plants (e.g., Hydrilla verticellata and Ceratophyllum demersum) is inhibited by high water turbidity. The annual flooding in the reservoirs is also effective in limiting and reducing the growth of submerged weeds. Mechanical control of floating weeds is occasionally practiced in some reservoirs. This type of control, however, is confined to a small area near the dam.

Since 1977, several biological agents have been introduced into Thailand by the National Biological Control Research Centre for controlling floating plants: water-hyacinth weevil (Neochetina eichhoniae) for controlling water hyacinth, the chrysomelid (Agasicles hygrophila) for controlling alligator weed, and the noctuid moth (Episammia pectinicornis) for controlling water lettuce. After careful study, it was evident that all of these agents could survive and become established under the environmental conditions of Thai reservoirs. They all successfully infested only the target plant. The water-hyacinth weevil, however, is rather slow in its control of water hyacinth; it will take 5 or 6 years to remove 25% of the water hyacinth from the infested area (Napompeth 1982). These three biological agents have been adopted by the Royal Irrigation Department and the Electrical Generating Authority of Thailand for the control of water hyacinth, alligator weed, and water lettuce in irrigation and hydroelectric projects.

Several herbivorous fish have been introduced into reservoirs to control aquatic weeds: grass carp (C. idella), Thai silver carp (P. gonionotus), Nile tilapia (O. niloticus), common carp (C. carpio), silver carp (H. molitrix), nilem (Osteochilus hasselti), and giant goramy (Osphronemus gouramy). These fish not only control aquatic weeds but also contribute to the food-fish production of the reservoir.

Regulation of Fishing Gear

Purse-seine, trawl, push-net, and bag-net fishing techniques are prohibited in the rivers, lakes, and reservoirs of Thailand. Beach seines with a mesh size less than 10 mm are also prohibited in the lakes and reservoirs of Thailand. These regulations were installed to protect against overfishing and to protect immature fish.

Restriction of Fishing Season and Area

In Thailand, the use of high-efficiency fishing gear (e.g., seine, bamboo-stake net trap, giant lift net) in freshwater is prohibited from 16 May to 15 September. This is the spawning season of freshwater fish in Thailand. This restriction ensures that spawning activities will not be disturbed. Fishing is also prohibited in rivers for a distance of 3 km downstream from a dam. This regulation protects migratory species.

The restriction of fishing areas and seasons in reservoirs may be unnecessary in Thailand because the fisheries depend on many species with short life spans. Most species reach maturity within 1 year and their spawning activities may extend throughout the rainy season (Bhukaswan 1983). In fact, fishing activity in the reservoirs is usually reduced during the rainy season because the fishermen are engaged in rice growing. In addition, the violent weather during this time keeps the fishermen off the reservoir. The rainy season is a good time to let fish spawn naturally in the reservoirs. However, protection of the spawning ground is considered an effective management tool in certain reservoirs (e.g., Ublrotana Reservoir; Pawapootanon 1982).

Prohibition of Destructive Fishing Methods

The use of poisons, explosives, and electric shock is prohibited in Thai reservoirs. These fishing methods kill fish and fish food organisms indiscriminately, and this endangers the existence of the fish stock. Furthermore, these methods cause long-lasting damage to the environment in general.

Conclusions

Reservoirs are an important fishery resource in Thailand. Fish yields usually peak within a few years of impoundment. Some reservoirs, however, reach their peak production in later years; the Ubolratana Reservoir for example, peaked in its 11th year. To maintain a high fish yield, several management techniques have been introduced and implemented by the Thai Department of Fisheries. These promising activities include a stocking program, the control of aquatic vegetation, the regulation of fishing gear, the restriction of fishing season and area, and the prohibition of destructive fishing methods. Several of the stocked fish showed good growth rates; however, only O. niloticus contributed significantly to the commercial catch of at least five multipurpose reservoirs. Submerged vegetation is controlled effectively by herbivorous fish, high-water turbidity, and rainy-season flooding. Floating vegetation is controlled effectively by natural biological agents (e.g., water-hyacinth weevil). The prohibition of fishing gear such as purse seines, trawls, push nets, and bag nets is essential to protect fish stocks; however, a size limitation may be unnecessary in tropical reservoirs because of their multispecific species composition. The closure of spawning grounds during the spawning season of valuable economic species is recommended. Destructive fishing methods (e.g., explosives) are prohibited in Thai waters.

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THE ROLE OF FISHERMEN IN IMPLEMENTING MANAGEMENT STRATEGIES IN THE RESERVOIRS OF SRI LANKA

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Abstract *The socioeconomics of six fishing communities in four man-made reservoirs of Sri Lanka was studied to investigate the potential contribution of fishermen to effective management. Adopting illegal fishing methods and changing fishing grounds are two of the socioeconomic indicators of low income derived from the fishery. The fishermen in all six fishing communities were willing to comply with any fishery regulation provided the fishermen unanimously agreed to the regulation. This suggests that effective management strategies, which will contribute to increasing the fishermen's income, can be implemented through properly organized extension societies in the reservoirs of Sri Lanka.*

In Southeast Asia, about 50% of fish production comes from small-scale fisheries and the management strategies for these artisanal fisheries should be viewed in the context of rural development (Marr 1982). Reservoir fisheries became established in Sri Lanka after coastal fishermen were attracted to the reservoirs in the 1950's because of their high yields. The introduction of the exotic cichlid Oreochromis mossambicus (Peters) in 1952 played a major role in the rapid development of the Sri Lankan reservoir fishery, the growth of which is well documented (e.g., Fernando and Indrasena 1969; Fernando 1977; De Silva and Fernando 1980; De Silva 1985). Information on the socioeconomics of these fishing communities (Fernando 1965), however, is scanty. This paper investigates the potential contribution of fishermen to effective fisheries management in the man-made reservoirs of Sri Lanka.

Materials and Methods

The socioeconomic data in this study were collected in November and December 1986 by interviewing fishermen (household heads of fishing families) in four man-made, Sri Lankan reservoirs: Kaudulla, Minneriya, Parakrama Samudra, and Pimburettewa. Because the fishermen are usually reluctant to reveal their actual income, the average daily income per fisherman derived from the fishery was computed from data obtained in a catch-and-effort survey in these reservoirs (U.S. Amarasinghe, unpublished) and from the average price per kilogram of fish at the landing sites. The marketing system at each reservoir was also investigated. Amarasinghe and Pitcher (1986) showed that fish-stock densities in the northern, middle, and southern basins of Parakrama Samudra were different; therefore, these three basins were treated separately in this study.

Data on the sociodemographic characters of the fishing communities, i.e., average family size, age structure, religion, education level, and nature of fishing occupation (full-time or part-time), were collected. Information pertaining to the fishermen's desire to change fishing occupations, to adopt illegal fishing methods (i.e., beach seining, use of gill nets of mesh size below 76 mm), and to migrate to some other area for fishing was also obtained. The fishermen's awareness of the rational utilization of the fishery resource and their willingness to comply with fishery regulations through an organized fisheries society were also investigated. In Pimburettewa, there is a well-functioning fisheries extension society that was organized by the government. Relevent information from the meetings of this society were extracted from the official records of the Sri Lanka Ministry of Fisheries.

Results

Pimburettewa had the highest percentage of full-time fishermen (92.2%); the southern basin of Parakrama Samudra had the lowest (27.3%) (Table 1). The average daily income per fisherman derived from the fishery ranged from LKR 34 in the southern basin of Parakrama Samudra to LKR 130 in Pimburettewa (in August 1987, 29 Sri Lankan rupees [LKR] = 1 United States dolalr [USD]) (Table 2). Except in the southern basin of Parakrama Samudra, the number of fishermen that desired to change their fishing occupation was negligible.

Fishermen in Kaudulla and Pimburettewa indicated that adopting illegal fishing methods such as beach seining, and using gill nets with mesh sizes below 76 mm is unnecessary because their average income is already relatively high (Table 2). Fishermen in the other reservoirs (72.7% in the northern basin of Parakrama Samudra), however, wished to increase their catches usng different fishing methods. Furthermore, the desire of the fishermen to migrate to another reservoir or floodplain varied from reservoir to reservoir (Table 2). The percentage of fishermen who wished to change either occupation, fishing method, or location was highest in the northern basin of Parakrama Samudra (100%) and lowest in Pimburettewa (8.3%).

In Pimburettewa, most of the fishermen sell fresh fish to a middleman, who markets it in urban areas, where demand is high. In the other reservoirs studied, the bulk of the catch was sold to fish vendors. During some seasons (especially during low-water months) there is a surplus production of fish at Kaudulla and Minneriya. This surplus, packed in ice, is transported by middlemen to urban areas on the west coast of Sri Lanka.

Although the level of education of fishermen is rather low (Table 1), almost all of them realized the importance of rational exploitation of the fishery resource (Table 3). Practically all the fishermen interviewed indicated a willingness to comply with fishery regulations imposed by the government through a fisheries extension society, either with no conditions (group 1) or with the condition that all the other fishermen are in agreement (group 2) (Table 3).

Table 1. Sociodemographic profile of the fishing communities in four Sri Lankan reservoirs.

	Reservoir[a]					
			PS			
	K	M	NB	MB	SB	P
No. of fishing families	114	95	11	30	11	86
Sample size (household heads)	92	40	11	27	11	84
Average family size	4.6	5.7	5.7	6.0	4.9	5.2
Education (%)						
Illiterate	12.0	7.5	-	3.7	-	1.2
Primary	54.3	52.5	45.5	51.9	54.5	52.4
Secondary	33.7	40.0	54.5	44.4	45.5	46.4
Higher than secondary	-	-	-	-	-	-
Full-time fishermen (%)	82.6	67.5	90.9	85.2	27.3	92.9
Part-time fishermen (%)	17.4	32.5	9.1	14.8	72.7	7.1

[a]K, Kaudulla; M, Minneriya; PS, Parakrama Samudra (NB, northern basin; MB, middle basin; SB, southern basin); P, Pimburettewa.

Table 2. Socioecomonic characters of the fishing communities of the four surveyed reservoirs.

	Reservoir[a]					
			PS			
	K	M	NB	MB	SB	P
Price of fish/kg (LKR)[b]	7	8	8	8	8	7
Average daily income per fisherman derived from the fishery (LKR)[b]	74	55	35	53	34	130
Fishermen (%) willing to:						
Change occupation (A)	9.8	5.0	0	0	36.4	3.6
Adopt illegal fishing (B)	0	15.0	72.7	18.5	18.2	0
Change fishing area (C)	2.2	5.0	72.7	33.3	9.1	1.2
Change A, B, or C	9.8	25.0	100.0	40.7	54.5	8.3

[a]Abbreviations as in Table 1.
[b]In August 1987, 29 Sri Lankan rupees (LKR) = 1 United States dollar (USD).

Table 3. Fishermen's awareness of the rational utilization of the fishery resource (positive awareness) and their potential contribution in implementing management strategies.

	Reservoir[a]					
			PS			
	K	M	NB	MB	SB	P
Positive awareness (%)	47.8	72.5	100.0	100.0	100.0	100.0
Potential contribution (%)[b]						
Group 1	65.2	32.5	9.1	25.9	36.4	32.1
Group 2	34.8	65.0	90.9	74.1	63.6	67.9
Group 3	0	2.5	0	0	0	0

[a]Abbreviations as in Table 1.
[b]Group 1, totally agree to comply with fishery regulations; group 2, agree to comply with fishery regulations if the other fishermen also agree; group 3, do not agree to comply with fishery regulations.

In Pimburettewa, the fishermen's extension society has implemented some positive management strategies: i.e., gradually increasing the minimum mesh size from 76 to 102 mm for the gill-net fishery, limiting the number of fishermen in the reservoir, and allowing only those fishermen who comply with the fishery regulations imposed by the society to fish in the reservoir. All the fishermen interviewed in this reservoir were willing to comply with any regulation that would increase their income. They also believed that the present regulation on minimum mesh size is useful in increasing their catches.

Discussion

Fishery management is usually mainly concerned with the rational exploitation of the fishery resource. However, it must be remembered that the participation of the fishermen is essential in implementing management strategies, especially in the artisanal fisheries of developing countries. This study indicates that any fishery regulation imposed by the government could only be effectively implemented through fishermen's participation. Nevertheless, organizing fishermen to form an extension society is possible only if they see obvious benefits in their participation.

The Pimburettewa Reservoir is good a example of how a functional fisheries extension society can positively influence the fishermen's income. This reservoir is situated in a relatively remote area. Therefore, an efficient method is essential for the disposal of surplus fish. The middleman plays a major role in this disposal. Also, because the middleman prefers large, fresh fish, which are more acceptable to the urban consumer, the fishermen tend to catch larger fish. The monthly mean landing size of *O. mossambicus*, which is the dominant species of the commecial fishery, range from 24.5 to 26.3 cm and the fishery of this reservoir has been shown to be optimally exploited (Amarasinghe 1987). The average daily income per fishermen (LKR 130) is the highest of all the reservoirs studies (Table 2). Being an active member of the extension society, the middleman is also involved in imposing fishery regulations. Although the middleman is motivated to increase his personal income by exploitation of the fishery resource, the fishermen equally benefit by increasing their catch. The existence of a successful fisheries extension society in Pimburettewa with minimal government intervention is a unique situation. Nevertheless, this system of management could be adopted in other reservoirs with active government mediation.

At the Kaudulla and Minneriya reservoirs, however, the disposal of surplus fish is unimportant to the middlemen. The main source of income for the middlemen at these reservoirs is marine fish marketing; freshwater fish ony become important to them when the marine fish production is poor. Therefore, the middlemen are unconcerned with the rational utilization of the fishery resource and the introduction of a middleman to such a reservoir could be detrimental.

Although the Ministry of Fisheries has organized extension societies in most major reservoirs in Sri Lanka, only a few function effectively. This study shows that practically all the fishermen are willing to comply with fishery regulations provided there is collective agreement among the fishermen. Therefore, the organization of fishermen into functional, effective extension societies will be helpful in implementing fishery regulations. Furthermore, by introducing insurance policies, maintaining effective marketing structures for fish catches, etc., the fishermen benefit directly from the society. Guidelines for the establishment and operation of extension societies can be found in Ben-Yami and Anderson (1985).

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THE NEED FOR RESERVOIR FISHERY MANAGEMENT IN BANGLADESH

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Abstract *Fisheries is second only to agriculture in the overall economy of Bangladesh, contributing 2.9% to the gross domestic product and accounting for over 9% of the nations' foreign exchange earnings. The total fish production of Bangladesh has declined over the past 10 years for the following reasongs: increased fishing pressure and lack of proper management practices; sedimentation of rivers and elimination of fishing grounds; large-scale reclamation of land for agriculture; etc. The primary source of fish production is the open-water capture fisheries in rivers, estuaries, seasonal floodplains, and natural depressions and man-made reservoirs. It is estimated that open-water capture fisheries covers an area of 4,268,740 ha. Man-made reservoirs in Bangladesh have a surface of 58,300 ha and an average production of 46 kg/ha. There are 31 commercially important species of which 5 are exotic. Oxbow lakes cover an area of 5488 ha and have an average yield of around 150 kg/ha. In some oxbow lakes, fish production has been increased by blending aquaculture techniques with fisheries management. As the habitat is continuously reduced there is a need to formulate a sound management program. Important considerations include the following: enforcement of fishery legislation; environmental engineering to improve the habitat; introduction of fish stocking and biological management programs. Realizing the need for sustained, increased fish production, the Fisheries Research Institute, Mymensingh, Bangladesh, is undertaking a comprehensive research program.*

Bangladesh is essentially a huge delta (143,998 km^2) formed by three main rivers, i.e., the Padma (Ganges), the Jamuna (Brahmaputra), and the Meghna, and their tributaries. The watershed of these rivers exceeds 1 x 10^6 km^2. In addition, the annual monsoons inundate approximately 49,000 km^2 from June to September, resulting in vast floodplains.

Fisheries, which is second to agriculture in the overall agrobased economy of Bangladesh, supports an estimated 1.1 x 10^6 full-time and over 10 x 10^6 part-time fishermen. Fisheries accounts for about 2.9% of the gross domestic product (GDP) and more than 9% of the nation's foreign exchange earnings. Fish account for about 6% of the per capita protein intake and about 80% of the animal protein intake of the people.

The total fish production in Bangladesh, in 1984/85 was estimated at 773,000 t, of which inland fisheries accounted for 588,000 t (76%). The daily fish consumption was estimated at 21 g/person in 1983/84; in 1963/64, the daily consumption of fish was 33 g/person. This decline in consumption is due to a decline in the total fish production (inland fisheries). There are four main reasons for this decline. First, there has been an increase in fishing pressure and a lack of management practices. Second, short-sighted leasing policies of public water bodies have led to overexploitation of fish resources. Third, sedimentation of rivers and canals has resulted in changes in water current velocity, the elimination of some spawning grounds, etc. Fourth, the ever-expanding flood-control and drainage programs have reduced the water area by 360,000 ha and, when fully implemented, will have diminished the total water area available by 2×10^6 ha; it is estimated that this loss of water area would decrease fish production by 250,000 t. Despite these problems, the combination of tropical climate, alluvial soils, productive waters, and vast floodplains helps Bangladesh to rank third in the world in inland fish production.

Because of the limited protein sources in Bangladesh and the reliance on freshwater fish as the main source of fish for domestic consumption, increasing inland fish production has become a priority in fisheries planning. By the year 2000, the population of Bangladesh will reach 128×10^6, placing pressure on existing fisheries to increase production. If the present daily consumption of 21 g/person is maintained, an extra 1×10^6 t will be required. Available information suggests that the potential for expansion of marine and estuarine fisheries is limited. Therefore, the bulk of the increase in production must come from inland waters (Table 1).

The objective of the second 5-year plan of Bangladesh (1980/81 to 1984/85) was to increase fish production from 650,000 to 1,000,000 t. The estimated total fish production of 773,000 t in 1984/85 indicates that only 35% of the targeted increase has been achieved. Realizing the need for optimizing the production and management of fisheries on a sound scientific basis, which was lacking in the past, the Government of Bangladesh established the Fisheries Research Institute in 1984 to develop fisheries techniques and management policies.

Table 1. Inland fisheries resources in Bangladesh.

	Area (ha)	**Total catch (t/year)**
Rivers including estuaries	1031563	207000
Beels and haors	114793	51660
Kaptai Lake	68800	4057
Seasonal floodplains	2832792	202000
Ponds	163492	105000
Oxbow Lakes	5488	862
Coastal aquaculture	51812	8228
Total	4268740	578807

Source: Bangladesh (1985).

Present Status and Research Needs

Reservoir Fishery

There is only one major reservoir in Bangladesh, the Kaptai Reservoir. With a surface of 58,300 ha (Table 2), the Kaptai Reservoir is the largest man-made lake in Bangladesh. It was created in 1961 by damming the River Karnafuli in the Chittagong Hill Tracts (22°29' N, 92°17' E). Although, it was primarily created for hydroelectric power generation, as well as for navigation, flood control, and irrigation purposes, the reservoir contributes substantially to freshwater fish production.

Unfortunately, as is the case with most Asian reservoirs, no preimpoundment survey was performed and fishery scientists were not involved in the planning stages. As a result, the reservoir was not cleared before submergence. This is now hindering fishing activities.

Sandercock (1968) and Mahmood (1986) recorded 58 fish species on the reservoir, if whch 31 are commercially important. Five of the exotic species (*Cyprinus carpio*, *Ctenopharyngodon idella*, *Hypophthalmichthys molitrix*, *Oreochromis mossmbius*, and *Oreochromis niloticus*) were introduced into the reservoir in recent years. Stocking the reservoir with fingerlings of catla (*Catla catla*), rohu (*Labeo rohita*), mrigal (*Cirrhinus mrigala*), silver carp (*H. molitrix*), grass carp (*C. idella*), and common carp (*C. carpio*) was initiated in small numbers in 1960/61 and has been continued sporadically.

Annual fish production ranged from 2145 to 4243 t from 1976 to 1985. In 1985, production drastically declined from 4243 to 2702 t. In 1976, carp (major and minor) accounted for 57% of total production; by 1985, this value had dropped to 18%. These data imply that the reservoir is being overexploited and, if appropriate measures are not implemented, fish production may further decline.

Except for a 1-year hydrobiological study of Kaptai Lake by the Aquatic Research Group of Chittagong University (Mahmood 1986), no studies have been carried out on the fisheries of the lake. Realizing the importance for adaptive research, the government established the Fisheries Research Institute in 1984. Identiying the need for

Table 2. Morphometric details of the Kaptai Reservoir.

	Mean value
Surface elevation (m)	31.1
Surface area (ha)	58300
Volume (hm^3)	524700
Total annual discharge (hm^3)	1707000
Storage ratio	0.31
Mean depth (m)	9
Maximum depth (m)	32
Outlet depth (m)	15.5
Mean annual water level fluctuation (m)	8.14

increasing and sustaining fish production from the reservoir, the Institute has initiated a comrehensive research program aimed at the following topics:

- determination of maximum fish-production potential;
- augmentation of fish production to the maximum sustainable level through natural and artificial means based on biological and environmental studies;
- establishment of an ecosystem-monitoring system that will suggest required adjustments to management practices;
- application of modern harvesting techniques to achieve maximum harvests;
- improvement of handling, processing, transportation, and marketing to ensure efficiency and product quality;
- dissemination of relevant information to members of the fishing community; and
- formulation of guidelines for the national development and management of reservoir fisheries.

Oxbow Lakes, Beels, and Haors

There is 5488 ha of perennial oxbow lakes in Bangladesh (see Table 1). These lakes have many uses: e.g., jute retting, irrigation water supply, and domestic use. The annual fish production from these lakes is around 862 t (157 kg/ha).

In addition to oxbow lakes, there are many water-filled depressions in the floodplain. These bodies of water, which are locally known as beels and haors, are flooded during the monsoon and are perennial. During the dry season, there is 114,793 ha of beels and haors (see Table 1), this area contributes 51,660 t (450 kg/ha) to the annual fish production of Bangladesh.

Beels, haors, and oxbow lakes can be managed in the same manner as a fishery reservoir. Fish production can be increased by blending aquaculture techniques of seed production and stocking with fisheries management. This style of management has been initiated in some areas and the annual production in three oxbow lakes has been increased from around 150 kg/ha to over 800 kg/ha.

Managment Needs

The problems involved in increasing fish production are not only biological but also involve financing, marketing, and socioeconomics. Therefore, to sustain and increase fish production in Bangladesh, it is essential that research on various aspects of reservoir management be initiated. The area of appropriate fishing grounds in Bangladesh is constantly decreasing. Therefore, a sound management program is needed to maintain both reservoir and floodplain habitats. The most important considerations in the formulation of such a program are the following:

- ° improvement and enforcement of fishery leglislation;
- ° environmental engineering to improve fish habitats;
- ° introduction of fish stocking and net, pen, and cage culture;
- ° protection of fish habitats such as spawning and grazing grounds; and,
- ° gradual replacement of revenue-oriented management with biological management.

Conclusions

Experience has shown that unmanaged fisheries almost always become economic and biological disasters. In a classic, one-species, capture fishery, with information on total catch and total effort, it is possible to manage the fishery and achieve the desired objectives. The fishery may be managed to maximize either production, economic yield, or employment. Additional information on year-class size, particularly before the year-class enters the fishery, growth rate, and natural mortality rate would permit fine tuning of the management scheme. The critical requirements to any management scheme is the basic information. Given the basic information, some additional research may be necessary to determine the relevant relationships in the particular resource fishery. In the absence of adequate information, interim management measures have to be developed on a pragmatic basis.

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FISHING TECHNIQUES IN CHINESE RESERVOIRS

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Abstract *This paper deals with fishing techniques in Chinese reservoirs. Although China has a long history of freshwater fish culture, reservoir fisheries is relatively new. The mean annual yield from reservoirs is now over 200,000 t. Various fishing techniques have been developed with a view to enhancing the stocks in reservoirs. Among them, the joint fishing method of blocking, driving, gill netting, and filtering is the most effective. It is a large-scale operation. The structures of the different nets and the operation of this method are discussed. The method is suitable for reservoirs with irregular bottom topography, width, depth, and fish distribution.*

Reservoir fisheries is an important component of Chinese freshwater fisheries. Although freshwater fish culture has a history of thousands of years, reservoir fisheries is relatively new in China. Reservoir fisheries have developed rapidly in China over the last 30 years. It is estimated that there are now 86,000 reservoirs of various kinds. Of these reservoirs, 2×10^6 ha of water surface is suitable for fish culture. At present, two-thirds of this area is being used. The mean annual yield from reservoirs is over 200,000 t, which is 10% of the freshwater fish production in China. Reservoirs are rich in aquatic resources and provide a suitable environment for fish production. The culture fishery in Chinese reservoirs is essentially stock and recapture.

The economic benefit of a fishery depends on the fishing effort, the control of predatory fish, etc. It is also advantageous to increase the survival rate of stocked fingerling. In China, methods have been developed to minimize the escape of fish from reservoirs and most fishing techniques have been developed with a view to enhancing the stocks in the reservoirs.

Artificial stocking is pivotal to Chinese reservoir fisheries. Stocked species such as silver carp, bighead, grass carp, and Wuchang fish are the main species utilized. Other economically important species include common carp, crucian carp, whitefish, mandarin fish and Elopichthys bambusa. The overall catch in most reservoirs consists mostly of fish with a small amount of rare aquatic animals, such as shrimp, crab, turtle, etc.

Nets are the most common fishing gear in Chinese reservoirs. Because various species are fished, several fishing methods are used. The stocked fish are caught by the joint fishing method of blocking, driving, gill netting, and filtering. This effective fishing method was established in the 1960s and has been developed gradually. Studies on reservoir fishing techniques in China are concentrated in this area. Other efficient fishing gear and methods include trawls, surrounding nets, pot filter nets, gill nets, and seines. The nets are made with twine, webbing, rope, floats, leads, etc. In addition, synthetic fibres such as polyamide, polyvinyl, and polyethylene are used.

Joint Fishing Method

The joint fishing method is a large-scale operation and is most efficient in catching fish such as silver carp and bighead that exhibit schooling behaviour. Schooling patterns change with physiological states and environment factors. In general, the annual activities of the fish can be divided into three migration states: spawning, winter, and feeding migrations. On the basis of migration, several kinds of fishing nets, which have different structures and roles, are separately set up in the same water body and the dispersed fish are made to gather gradually (Fig. 1). Finally, the fish are forced into fixed filter nets. This method is suitable for reservoirs with irregular bottom topographies, widths, depths, and fish distributions.

The main fishing gears used in the joint fishing method are the trammel net, the set-impounding net, and the fixed filter net. The dimensions of the nets, the depth of operation, and the mesh sizes depend on funds, water surface area, size of the fish caught, etc. (Xu 1983; Li and Xu 1988).

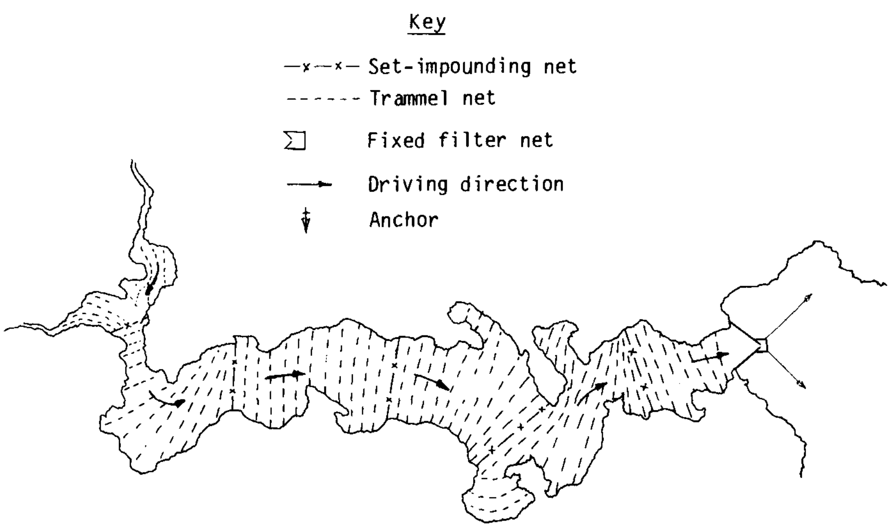

Fig. 1. Operation of the joint fishing method.

Trammel Net

The trammel net consists of a loosely set fine-meshed net (inner net) and two wide-meshed outer nets (Fig. 2). The three nets are attached to a head rope and a foot rope. The twines of the outer nets are thicker. The inner net, with thinner twine, is braided with nylon twines. The length of the nets is 50 m; the height, 8-12 m. The number of trammel nets used varies with the dimensions of the water body. The principle of the trammel net is as follows: when a fish swims up against the net, it draws the mesh of the inner net through one of the meshes of the outer net and becomes caught in the resulting pocket of netting. When caught on a trammel net, silver carp and bighead tend to struggle. As a result, the surrounding shoal of fish move rapidly.

Set-Impounding Net

A set-impounding net is a long and narrow single wall of webbing (Fig. 3). The length and height of the net depend on the width of the water body and the mean water depth. When setting the net, the ends of the net are drawn to each bank of the reservoir. The float line, which has sufficient buoyancy, ensures that the net will not sink. A heavy lead line lies on the bottom of the reservoir. The function of the net is to close the fishing ground and encircle schools of fish. When the area of the fishing ground is gradually reduced and dispersed fish are concentrated into a fixed net, a trammel net is set.

Fixed Filter Net

The fixed filter net is similar in appearance to a rectangular cage (Fig. 4); however, the top of the net is open. It consists of bottom, side-wing, wing-end, and leader nets (Fig. 4). The length,

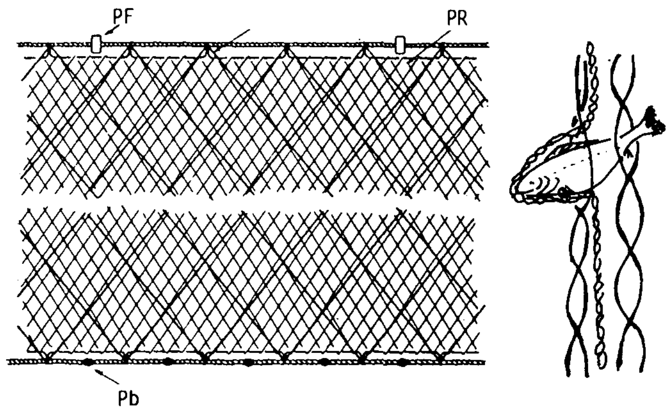

Fig. 2. Trammel net. PR, polyethylene rope; PF, plastic float; Pb, lead weight (Xu 1983).

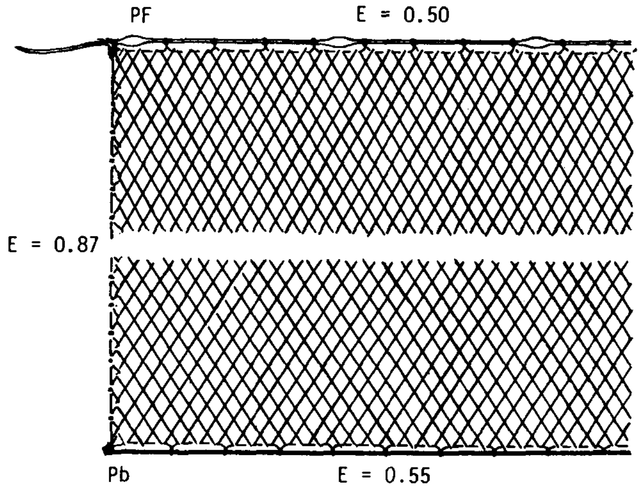

Fig. 3. Set-impounding net. PF, plastic float; Pb, lead weight (80 g); E, hanging coefficient.

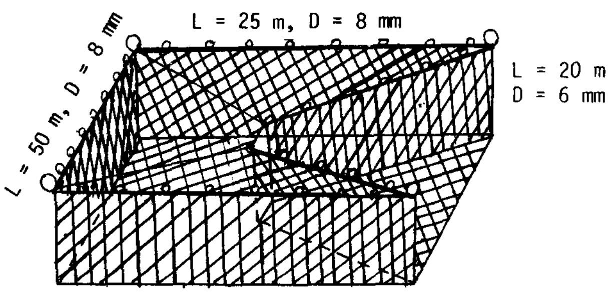

Fig. 4. Fixed filter net. L and D represent the length and diameter of the polyethylene rope, respectively.

width, and the depth of the net cage depends on the type of reservoir and the amount of fish stocked. The net acts as a containment area for the fish being caught.

Trawl Net

Silver carp, bighead, and various bottom-dwelling species are caught by the improved trawl net (Table 1), which can either be operated throughout the water column or on the bottom of the reservoir. Both the opening of the net and the depth of fishing are regulated by "danleno" (spreaders) and floats (Fig. 5). A new, four-panel trawl net with a large mesh size was tested at different times in various reservoirs, and very good harvests were obtained. The advantages of this new trawl net are its simple structure, its light weight, as well as its low cost, good results, and convenient operation (Wang 1985).

Table 1. Characteristics of trawl, surrounding, and pot filter nets.

Net	Species caught	Fishing period	Reservoir suitability[a]	Required vessel(s)	Required labour
Trawl net	Silver carp, bighead	All year	L,M	Two 40-hp boats; 20 t capacity each	8-10 persons
Surrounding net	Silver carp, bighead, whitefish	October-March	L,M	One 60-hp boat, four or five 1.5-t capacity boats	10-12 persons
Pot filter net	Silver carp, bighead, mud carp, common carp	-	-	Two 1-2 t capacity boats	5-6 persons

[a]L, large reservoir (>6700 ha); M, medium reservoir (670-6700 ha).

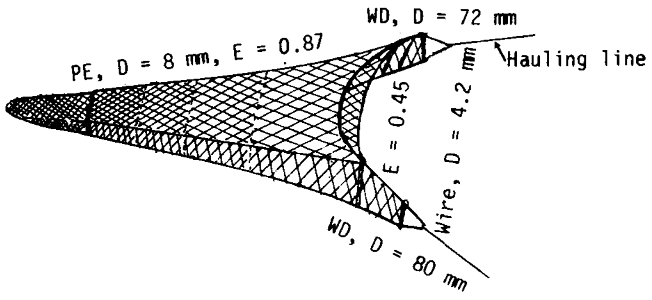

Fig. 5. Trawl net. WD, wooden "danleno" (spreader); E, hanging coefficient; D, diameter; PE, polyethylyne.

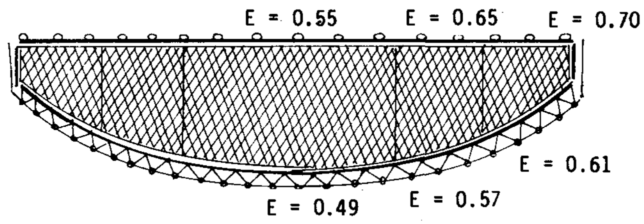

Fig. 6. Surrounding net. E, horizontal hanging coefficients (for top and bottom of net).

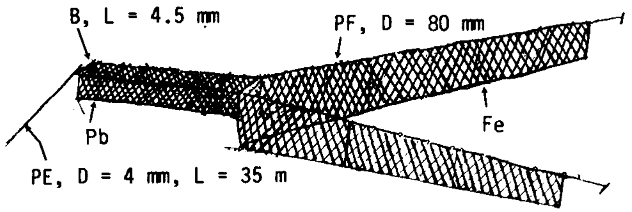

Fig. 7. Pot filter net. Pb, lead weights (1 kg); Fe, iron weights (3 units/m, 100 g/unit); PF, plastic float; B, bamboo pole; PE, polyethylene; L, length; D, diameter.

Surrounding Net

The traditional marine surrounding net is an efficient tool for catching silver carp, bighead, and whitefish in reservoirs (Table 1). The net is constructed like a purse seine. The centre part of the net is higher than the ends of the net (Fig. 6). The lower edge hangs down in the water and has a series of iron rings through which a purse line runs. The operational principle of the net is as follows: the net is laid/set in a circle around the fish shoal; after the fish have been encircled, the purse line is tightened, closing the net at the bottom. The catch is then hauled in (Xu 1983).

Pot Filter Net

According to the pattern of fish activities, the pot filter net is set up on the way of fish migration and habitat. The fish schools, stimulated by the current, swim against the wing of the net. A long leader net guides the fish to the entrance, which opens into a chamber. The advantages of the net are its savings in labour, the fresh catch, its simple operation, low cost, etc. (Fig. 7). The dimensions and structure of the chamber of the net are as follows: 30 x 4 x 4 m, wing; 24 x 12 m; twine materials, polythylene and polyamide; mesh size, 3 cm (Zhu 1982).

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FISH PRESSURES ON ECOSYSTEMS: DYNAMIC, HOLISTIC INDICES

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Abstract *Three dynamic, holistic ecosystem indices are recommended for quantifying the degree of fish predation pressure that exists in fish-stocked tropical water bodies or in water bodies likely to be stocked. These indices were first suggested and developed by Hrbacek's school of limnology in Czechoslovakia for European carp culture ponds and riverine reservoirs. The paper attempts to make some preliminary evaluations as to their applicability and usefulness for fish-stocked tropical waters. The paper recommends the calibration of these indices in a range of tropical waters with different and known fish-stocking levels and points out the need for much more quantitative research on tropical zooplankton.*

The main aim of fisheries management is to enhance fish yields in various ways that usually result in establishing fish stocks of high densities. We are examining how high fish densities can affect the biological structure and functional dynamics of the water body concerned. Apart from fish culture ponds, it is rare that the densities of fish populations have been estimated and, in Asia, more and more attempts are being made to expolit the availability of ancient irrigation reservoirs or the newly built multipurpose reservoirs for freshwater fisheries to supplement the diet of local communities. It would be useful, therefore, to have some limnological measures or indices that quantify the ecosystem's response to the imposition of fish predation or grazing pressures.

More is known about the effects of high fish stocks on the biological structure and functional dynamics of water bodies in the temperate region than in the tropics. Therefore, we start with a hypothesis on this topic that was developed in Europe and later consider whether is is applicable to tropical water bodies exploited for fisheries. This hypothesis was developed by Jaroslav Hrbacek. He applied his ideas to studying the effects of fish stocking on the ecology of riverine reservoirs largely used for hydroelectric purposes. Some of his concepts are fundamental and can be applied to tropical water bodies.

The fry of most European cyprinid fish species have a phase of eating crustacean and other kinds of zooplankton. Older and larger stages of fish such as roach, bleak, perch, and bream are also forced to consume crustacean zooplankton when stocked in very dense conditions. Hrbacek et al. (1961) and Hrbacek (1962) state that, when subjected to ever-increasing pressures of fish predation because of increasing dense fish stocking, the water body shows some of the following responses.

Firstly, there are changes in the size structure and species composition of the zooplankton community. At low fish stocks, the predominant planktonic species consist of large-bodied forms >1 mm in length, but these are replaced by forms with smaller body sizes (<1 mm length) and, under extremely high fish stocking, the predominant zooplankton may consist of small rotifers and protozoa.

There is, therefore, a change in the nature of the zooplankton accompanying the reduction in body size of the predominant forms. The genus Daphnia is the main genus that contributes significantly to the zooplankton community under low fish pressure, ranging from large species such as D. magna and D. pulicaria to, with increased pressure, smaller species such as D. hyalina, D. cucullata, and D. galeata. With the increased fish pressure, the Daphina genus is replaced by smaller cladocerans such as Ceriodaphnia spp. and Bosmina spp. Despite these changes in the species composition and size structure of the zooplanktonic community, the zooplanktonic biomass (milligrams N per litre, Kjeldahl N) remains more or less constant for any particular water body at a level that is about 11% of the concentration of total nitrogen (dissolved and particulate).

A second response to increasing fish pressure is an enhancement of the metabolism or turnover rate of the water body; this can be detected as a greater community respiration. The reasons for this are complex and not full detailed but can be readily demonstrated in the magnitude of the nightly decrease in dissolved oxygen as a measure of community respiration.

There are many characteristc biological changes associated with this response. The large Daphnia species and individuals that can exist only at low fish densities are efficient filter-feeders on small, grazeable, planktonic algae. This removes from the phytoplankton the algal species that are most efficient at nutrient uptake and light capture, resulting in high chlorphyll a specific photosynthetic rates. The large ungrazeable algael species remain. Released from the smaller competitors, these large algae dominate the phytoplankton community, although usually at low chlorphyll a biomasses. This is accompanied by high secchi disc depths because large algal species are inefficient at light capture.

In contrast, small-bodied cladocerans (or rotifers under more extreme conditions) that can exist under increased fish pressures are less efficient at reducing the population densities of small algal species, which they also eat. The small algae can, therefore, compete with the larger algal species for nutrients and light, and develop high chlorophyll a biomasses, resulting in a low secchi disc depth. The disburbance of the bottom organic sediments by the feeding activities of dense populations of fish such as carp would also contribute to an enhanced community respiration.

It took a long time to demonstrate and test this hypothesis and Hrbacek has now exploited these ecosystem responses to fish pressures by proposing several simple ecosystem indices that could both demonstrate and quantify the responses of water bodies to different levels of fish stocks. There are three indices.

First, there is zooplankton body size; two ratios are used, the second being more sensitive.

$$\frac{\text{Biomass of large cladocerans } (>0.71 \text{ mm})}{\text{Biomass of total zooplankton}}$$

or

$$\frac{\text{Biomass of large cladocerans } (>0.71 \text{ mm})}{\text{Biomass of total cladocerans}}$$

A quick method for separating cladocerans and copepods from a net sample of zooplankton was developed in Hrbacek's laboratory (Straskraba 1964; Edmondson and Winberg 1968) and can be extended to deal with extracting crustaceans from a blue-green phytoplankton bloom. The larger cladocerans are separated from the others by seiving.

The second index is the nightly decrease in dissolved oxygen concentration in the surface waters of a water body. According to Hrbacek (1969), this nightly decrease in dissolved oxygen concentration is twice as great in highly stocked fish ponds (10^4 fish/ha of small cyprinids, 2.5 mg O_2/L) as in ponds with few fish (10^3 fish/ha, 1.3 mg O_2/L).

Third, there is the ratio of chlorphyll a to total phosphorus.

$$\frac{\text{Average chlorphyll a in the euphotic zone during the vegetative season}}{\text{Total phosphorus concentration (TP) during its spring maximum}}$$

The total phosphorus technique measures both dissolved and particulate phosphorus and provides an estimate, like the Kjeldahl nitrogen method mentioned earlier, of the nutrient status of the water body. This index exploits the existence of the Dillon-Rigler regression (Dillon and Rigler 1976), demonstrated for many temperate lakes.

Examples of the application of these indices in temperate water can be found in Hrbacek et al. (1978) and Hrbacek et al. (1986). Two large reservoirs in Czechoslovakia are compared over a long period of time (1975-83). In one, where the normal high fish predation by perch and roach fry reduce the size of the predominant cladoceran zooplankton, chlorophyll a attains a level expected by the Dillion-Rigler regression for the amount of total phosphorus present. In the other reservoir, where large-bodied cladoceran zooplankton existed because of piscivore control of the cyprinid fry densities, the chlorophyll a level fell well below the Dillion-Rigler regression value. A similar situation was observed in Parakrama Samudra, an irrigation reservoir in Sri Lanka, in 1980 and 1982. The chlorophyll a levels were lower than expected for the total phosphorus concentration present in 1980 when there was every indication that stocks of <u>Oreochromis mossambicus</u> were high; commercial yields of 376 kg/ha were recorded (De Silva 1985) and catches of the noncommercial size of 10 cm were 10 times greater than in 1982 (F. Schiemer and R. Hofer, personal communication). In addition, there were large numbers of another detritivorous fish feeding on the planktonic seston, Amblypharyngodon melettinus (Schiemer 1983). Nevertheless, in 1982, the chlorophyll a values fitted the Dillon-Rigler line, when the commercial yields from the reservoir were greatly reduced (120 kg/ha; Amarasinghe 1986) and relatively few 10-cm O. mossambicus were present. This is probably the first example of a fish grazer affecting the chlorophyll a - total phosphorus relationship.

Examples of the nightly decrease in dissolved oxygen concentration were found in an undated Oglesby report for fish ponds at the Udawalawe Fisheries Station in Sri Lanka. The decrease was 3 mg O_2/L in a pond containing 265,000 bighead carp fry but only 1.7 mg O_2/L in another pond with 140 grass carp. During a diurnal study carried out in Parakrama Samudra in September 1979, the nightly decrease in dissolved oxygen was 4.5 mg O_2/L (Schiemer 1983), which implies the presence of high fish stocks. All these nightly decreases for tropical waters are quite large compared with those cited by Hrbacek earlier (2.5 and 1.3 mg O_2/L).

The overwhelming dominance of herbivorous-detritivorous fish such as O. mossambicus and other cichlids in the commercial yields of stocked tropical waters might suggest that Hrbacek's zooplankton index is not relevant. Moreover, the relatively sparse contribution of the genus Daphnia to tropical zooplankton (Fernando 1970a,b) might seem to remove one of the more important indicator genera. It is true, however, that the scarcity of Daphnia has not been fully explained and could be due to the relatively high fish densities that seem to occur commonly in tropical waters. One could postulate that the scarcity of Daphnia spp. is an indication of this. An additional difficulty in calculating a size-based zooplankton index for tropical waters is the fact that the most frequently occurring tropical planktonic cladocerans consist of small species. Experimental work on Sri Lankan Diaphanosoma excisum, Ceriodaphnia cornuta, and Moina micrura by Jayatunga (1986) has shown that a reduction in size can occur (under the influence of food limitation, in this case) but to an extent that is less easily measureable than the larger, temperate cladocerans.

There still remains the possibility that a change in the species composition of the zooplankton community can be used to indicate the degree of fish predation pressure. An example of this is the predominantly rotiferous and protozoan zooplankton community that was recorded in Parakrama Samudra in 1979, 1980, and 1982 (Duncan and Gulati 1971; Duncan 1983, 1984). This contrasts greatly with the crustacean zooplankton recorded by Jayatunga (1982) for Kalawewa and by Vijverberg et al. (this volume) for five southern reservoirs. Crustacean species did exist in the zooplankton of Parakrama Samudra but at a low background level. It is unlikely that the species composition was caused by the grazing activities of the herbivore-detritivore O. mossambicus. During 1979, 1980, and 1982, the presence of a small pelagic clupeioforme fish (Ehirava fluviatilis) was discovered (Duncan and Gulati 1981; Duncan 1984). It was present in high densities (170 individuals/m^3 in 1982) and high biomass 8 g/m^2 or 80 kg/ha). It matures at 16 mm, is planktonic from the newly hatched larva of 2 mm to the spawning adult (16-20 mm), and appears to have a life cycle of 1 month (Newrkla and Duncan 1985).

Therefore, its potential yield is high. Gut analyses show that *E. fluviatilis* eats planktonic rotifers, mostly *Trichocerca* and *Brachionus* spp. (Duncan 1984). It is suggested that the presence of high densities of *E. fluviatilis*, a truly zooplanktivorous species, was responsible for reducing the crustacean zooplankton and for the present composition of rotifer and protozoan species. It is not known whether *E. fluviatilis* was present in the Sri Lankan reservoirs studied by Vijverberg et al. (this volume) but a search in the Kalawewa Reservoir showed it to be absent.

The species composition and size structure of zooplankton communities are so sensitive to top-down fish predation pressures that it would be worthwhile to develop a tropical zooplankton index calibrated against fish biomass or stocking density. Quantitative studies on tropical zooplankton are a neglected areas of aquatic research, despite their importance as food for fish larvae and fry. In fact, the calibration of all the dynamic, holistic indices suggested in this paper against fish stocking levels would be a useful future research activity. Some crucial limnological measurements that are required to gain an understanding of ecosystem dynamics and the

Table 1. Crucial measurements to understand the ecosystem dynamics and structure of tropical, fish-stocked water bodies.

Physical	Chemical	Biological
		Phytoplankton
Basin morphology	Total phosphorus[a]	Dominant species and groups; sizes and shapes (colonial, filaments)
Ligh penetration (secchi disc depth)[a]	Total sestonic carbon[a]	
Wind mixing	Chlorophyll a[a]	
	Primary productivity	
		Zooplankton
Temperature and thermal stratification[a]	Dissolved oxygen (including the nightly decrease)[a]	Dominant species (crustacean or rotifer)
		Proportion of filter feeders
		Body sizes (large or small)
		Biomass of cladocerans[a]
		Fish
		Dominant species; density and biomass[a]
		Feeding types
		Spatial and temporal distributions
		Reproduction in reservoir

[a]Crucial measurements for frequent monitoring. The other parameters represent special studies.

structure of the water bodies in which it is planned to stock commercially viable fish species are listed in Table 1. Many are useful for monitoring the nutrient status and health of a water body from the point of view of the health of its fish population. Other measurements are more time consuming but do not need to be done at regular intervals and, thus, represent special studies that could provide insight.

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THE SIGNIFICANCE OF THE ECOSYSTEM APPROACH FOR RESERVOIR MANAGEMENT

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Abstract *On the basis of a Sri Lankan case study, this paper discusses the relevance of a holistic approach for fisheries management. It analyzes species composition, size, structure, and biomass distribution of the fish fauna, as well as some of the network fluxes (especially primary productivity and predation by cormorants). Management aspects are considered with regard to the carrying capacity for Oreochromis mossambicus, the introduction of exotics, and the exploitation of unconventional fish resources.*

This paper outlines the importance of a holistic approach for reservoir management, especially with regard to fisheries, on the basis of results obtained from our study on Parakrama Samudra, an ancient man-made reservoir in Sri Lanka (Schiemer 1983). From a fisheries point of view, an ecosystem-oriented approach is of relevance for two main reasons:

- to improve and optimize fisheries exploitation; and
- for an understanding of the effects of fisheries management practices on the aquatic ecosystem, its community structure, and metabolism.

For example, it is significant to predict before its introduction the possible effect of an exotic species on the trophic state of a body of water. Natural conservation, the endangerment of indigenous species by the introduction of exotics, is also part of this aspect. This paper concentrates on the first aspect. The second topic is discussed by Duncan and Schiemer (this volume).

The type of questions that require a holistic approach in fisheries can be illustrated using the example of Sri Lankan reservoirs. It is well known that Sri Lanka has no natural lakes and, therefore, no indigenous lacustrine fauna (Deraniyagala 1952; Munro 1955; Fernando and Indrasena 1969). This fish fauna of the reservoirs, therefore, consists of three elements according to their origin: indigenous riverine and marsh-dwelling forms, invaders from brackish water estuaries, and introduced exotics.

The reserovirs, although mainly built in ancient times, are young in evolutionary terms. Therefore, several niches may be unoccupied.

This is considered the reason for the success of exotics, especially of *Oreochromis mossambicus*, in the reservoir fishery of Sri Lanka (Fernando 1971; De Silva 1985). Many other exotic fish species have been suggested for introduction and many species have been stocked, e.g., in Parakrama Samudra (PS), without success. To determine why *O. mossambicus* is a successful species in Sri Lanka while other species are not and to what extent the productivity of *O. mossambicus* is higher than that of the indigenous forms requires an ecosystem-oriented approach.

To optimize fisheries, studies oriented toward the following areas are essential:

- the trophic requirements of fish species in qualitative and quantitative terms (e.g., food selection, feeding rates);
- the community structure of the fish fauna with regard to its species composition, size structure, distribution pattern, and temporal dynamics;
- the resources base for various trophic guilds of species, its productivity, dynamics, and the effect of environmental variables on them; and
- the environmental factors essential for the population dynamics of the major species of fish, e.g., physicochemical characteristics, biological interaction by predation, and competition.

Community Structure of Fish

The community structure of the fish fauna and its trophic requirements are discussed using the example of PS. The following considerations are a synopsis of the results of an extensive fishing program in the course of three research periods (Aug.-Sept. 1979, Mar.-Apr. 1980, July-Aug. 1982). Experimental fishing was carried out mainly with gill nets of different mesh sizes and with Bongo nets (Schiemer and Hofer 1983; Newrkla and Duncan 1984). A detailed account of the trophic classifcation of the main species has been given by Schiemer and Hofer (1983). Phytoplankton production is used either in suspended form (*Amblypharyngodon melettinus* (Val.)) or in the form of flocculant material (the benthic detrital aggregate; Bowen 1979) in the sediment surface (*O. mossambicus*).

Zooplankton is consumed by juvenile states of *O. mossambicus* and *Rasbora daniconius* as well as by some brackish-water species colonizing the reservirs from estuarine habitats (e.g., *Ehirava fluviatilis*, Hemiramphidae sp.). The latter occurs in some reservoirs in high densities and forms the basis of a viable fisheries. Smaller zoobenthos is heavily predated by several minor species of barbs (*Barbus dorsalis*, *Barbus chola*).

Several species of fish (i.e., *Etroplus suratensis*, *Barbus sarana*, *Barbus filamentosus*, *Labeo dussumieri*), some of which are economically important, show a predominance of inshore feeding sites as well as inundated zones with submerged trees. This guild feeds on macrophytes, plants, and "auwfuchs" (periphyton). The whole group consists of prospective candidates for new reservoirs with submerged trees.

The significance of piscivorous fish in Sri Lankan reservoirs is not well studied. Some of the small species (e.g., R. daniconius) are important predators on fish fry in the littoral zone, especially of O. mossambicus, and regulate their population density. The numerical importance of larger predators (e.g., eels), their economic potential, and their effect on the ecosystem structure is at present unknown.

Considering the size structure of the fish fauna, a remarkable range is evident within the abundant forms, from the clupeoid Ehirava fluviatilis with an adult size of >16 mm (Duncan 1983; Newrkla and Duncan 1984), pelagic mass fishes A. melettinus and R. daniconius with a size at maturity <60 mm, up to O. mossambicus (size at maturity, 150 mm; Amarasinghe, this volume). Figure 1 provides some information on the size selectivity of gill nets of mesh sizes used (see De Silva and Sirisena 1987); the absence (or paucity) of the young stages of indigenous barbs in the reservoir is also shown. It has been

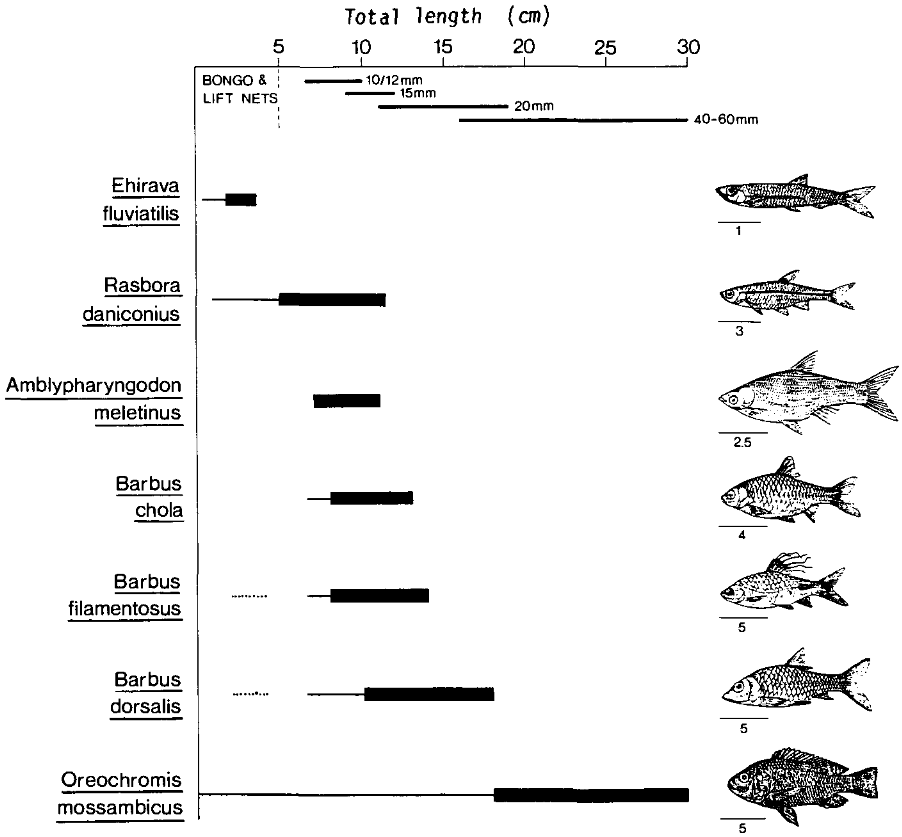

Fig. 1. Size structure of the numerically abundant fish species of Parakrama Samudra, Sri Lanka. Thin line, juveniles; thick line, adults; dotted line, rare occurrences.

established that those riverine and potamodromous forms migrate upstream for spawning before the onset of the northeast monsoonal rains (De Silva 1983; Silva and Davies 1986).

Abundance and Biomass Distribution

A truly numerical analysis of the fish fauna is not available for any Southeast Asian reservoir. The relative abundance of various species in PS can be estimated from the catch per unit effort (CPUE) values of extensive gill-net surveys (means, maximal numbers per net per hour) during the three research periods in 1979, 1980, and 1982. Only for the clupeoid Ehirava fluviatilis have absolute densities been established with Bongo nets and the Clarke-Bumpus plankton sampler. The CPUE values are subject to large seasonal and spatial variations. From the 3 years of catch statistics, a tentative ranking of numerical abundance can be given (Table 1).

De Silva and Sirisena (1987) found similar assemblages of species in a survey using multimesh gill nets in four reservoirs in southern Sri Lanka, indicating the existence of a species-association characteristic of the shallow lowland reservoirs of the country. Considerable differences were observed in the fauna composition of a deeper reservoir of the same area. Figure 2 presents a biomass pyramid constructed from CPUE data (offshore zone of PS north) and the mean body weight of fish caught with different mesh sizes. Three groups are distinguished: the pelagic forms (A. melettinus, R. daniconius), the minor barbs (B. dorsalis, B. chola, B. filamentosus), and O. mossambicus.

In 1980, only catches during the day have been carried out with small-meshed gill nets, underrepresenting A. melettinus, which has a strictly nocturnal activity pattern. Two important conclusions can be drawn from Fig. 2. First, commercial fisheries use only a small portion of the CPUE pyramid, both in terms of biomass and in the number of species caught; practically none of the indigenous mass

Table 1. Abundance (catch per unit effort per net per hour) of fish in Parakrama Samudra.

Species	Size (mm) 10	15	20
Amblypharyngodon melettinus	906		
Oreochromis mossambicus			64[a]
Barbus filamentosus	552		204
Barbus dorsalis			130
Barbus chola		80	
Rasbora daniconius	72		
Ehirava fluviatilis		70 individuals/m^2	

[a]The high population densities of fish fry in the littoral zone have yet to be quantified.

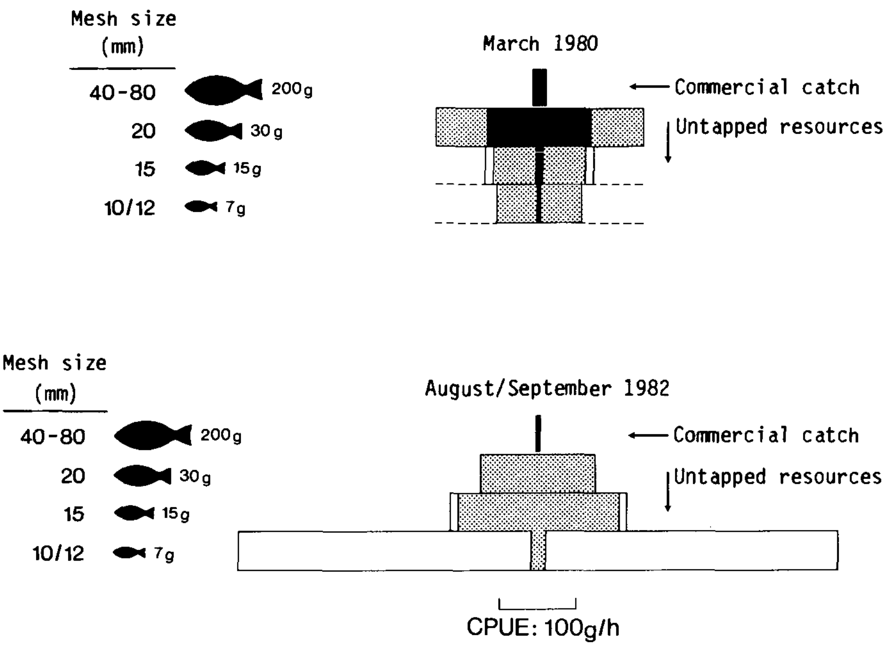

Fig. 2. Biomass pyramids in terms of the catch per unit effort (CPUE) of different mesh sizes of gill nets. The average body weights of the individual fish are indicated (see text for further explanation).

species is represented in the commercial catch. Second, disntinct seasonal differences occur in the catch statistics and in the population structure are obvious in various species (e.g., in O. mossambicus, a considerable population density of middle-sized juveniles was found only in 20-mm gill nets in March-April 1980 but none was found at the two other sampling periods; similar changes in the population structure were also observed in all three species of minor barbs).

Network Fluxes

From a management point of view, it is crucial to understand the production of the resource base that determines the carrying capacity of fish, as well as predation effects. Figure 3 presents a simplified diagram of the network flow, mainly of the open lake community. Its energetic basis is the primary production of the phytoplankton sustaining a pool of organic seston (algae, detritus, and bacteria). This compartment is maintained in the shallow, tropical water bodies via sedimentation, diurnal convectional currents, and wind directly coupled to the boon zone (Viner 1975; Bauer 1983; Schiemer and Duncan 1983). The regulation of primary production in those shallow irrigation reservoirs is not yet fully understood. It is dependent on an array of external influences and internal processes (Fig. 4).

The areal production (P_a, grams C per square metre per day) is a product of the phytoplankton biomass (B) and its specific turnover rate (P_s). This specific activity is determined by the community

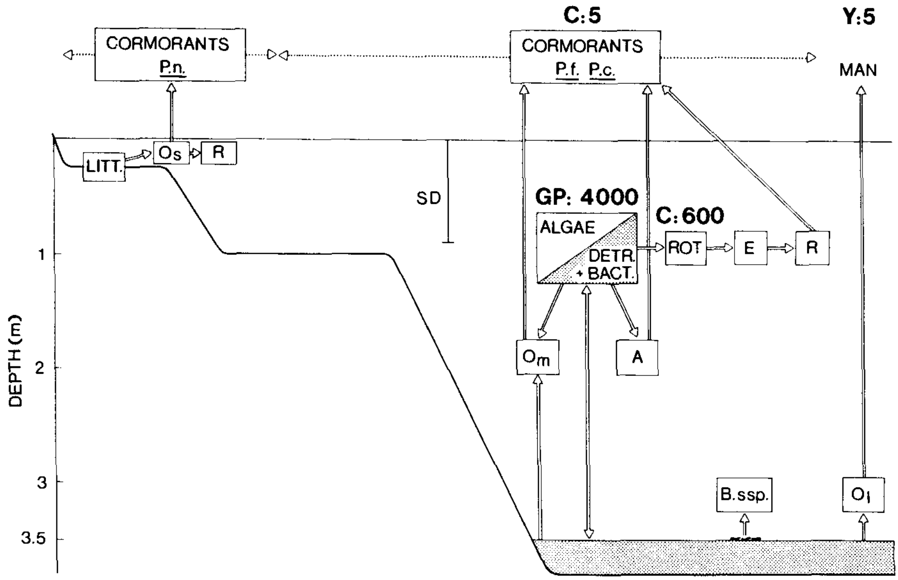

Fig. 3. Network fluxes (mg C/m^2 per day) in Parakrama Samudra: GP, gross primary production; C, food consumption; Y, fish yield; LITT, littorial algae and invertebrates; O_s, O_m, O_e, *O. mossambicus*, small, medium, and large, respectively; ROT, rotifers; A, *Amblypharyngodon*; E, *Ehirava*; R, *Rasbora*; B.spp., *Barbus* species; SD, secchi disk depth; dotted lines, feeding zones of the three cormorant species (P.n., *Phalacrocorax niger*; P.f., *P. fuscicollis*; P.c., *P. carbo sinensis*).

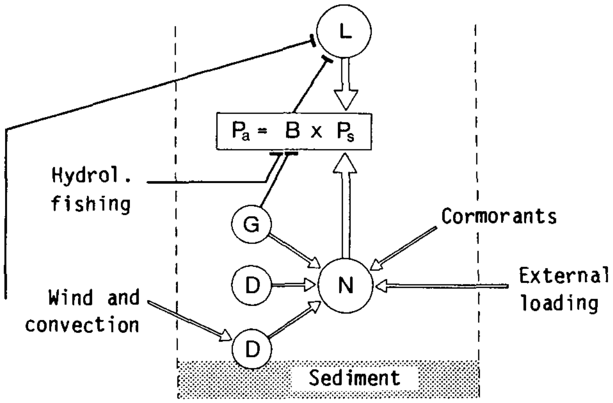

Fig. 4. Regulation of primary production. P_a, areal production; B, phytoplankton biomass; P_s, turnover rate of B; L, light conditions, N, nutrient availability; D, decomposition; G, grazing.

structure of the phytoplankton association, by light conditions (L), and by nutrient availability (N). The latter is a result of external loading because of inflow, seasonal flooding of draw-down areas used as pastures, and terrestrial erosion, mainly in the monsoon period.

The nutrient availability is to an even larger extent influenced by the internal loading, i.e., the nutrient recycling (Viner 1975) because of decompositon processes (D) and grazing (G) in the limnetic zone, defecation of fish-eating birds, and nutrient release from the sediments. This latter process is enhanced by water currents because of diurnal convections and wind. Its importance is strongly linked to the depth of the water column and, thus, varies considerbly with the water-level fluctuations induced in the shallow reservoirs by the needs for irrigation.

From the results of Dokulil et al. (1983), the following quantitative conclusions can be drawn with regard to the situation in PS. First, the average level of algal biomasses and areal production in PS (and in similar shallow lowland reservoirs; see Silva and Davies 1986) is high, but values varied considerably between visits (Table 2). Second, the biomass values are, however, lower than B_{max} (maximal sustainable areal biomass) values predicted from Steel's model (1975) on algal productivity in reservoirs based on the light-extinction coefficients and the depth of the mixed water column. These differences between the predicted B_{max} and the actual values found can be due to nutrient limitations or biomass losses because of outflow, grazing, and sedimentation. A diurnal pattern of nutrient limitation is indicated by hydrochemical indicators (see Dokulil et al. 1983; Gunatilaka 1985). Grazing effects are severe. Quantitative studies on planktonic rotifers indicated that a high proportion of the net primary production is grazed by zooplankton (see Fig. 3).

One of the relevant questions for fisheries is to what extent this primary production level sustains the populations of O. mossambicus. The overall success of this species in the fisheries of Sri Lankan reservoirs has been attributed to a combination of factors (Fernando and Indrasena 1969; De Silva 1985):

- their high trophic state;
- the lack of strong indigenous competitors (an argument that does not hold in the light of our results);
- the fishes ability to switch food sources (for a discussion, see Maitipe and De Silva 1985); and
- the regulation of population densities by physical conditions, i.e., water level fluctuations an by a high predation pressure.

De Silva (1985) proposed the hypothesis that, under Sri Lankan reservoir conditions, O. mossambicus is rarely food limited. In this respect, it is of interest to consider the energetic limitations of O. mossambicus under Sri Lankan reservoir conditions. The following consideration is based on data of energy requirements of growing, middle-sized juveniles (20 g fresh weight) under field conditions in PS (Hofer and Schiemer 1983). Daily consumption rates are 8 kJ/fish. Only 3 kJ is assimilated (37.5%), the unassimilated part is returned in the form of feces and excretory products to the energy pool available for the food chain; 1.2 kJ is channeled into growth. This energetic requirement of an individual juvenile fish can be compared with a daily gross primary production of 117 kJ/m^2 and a net primary production of 33.5 kJ/m^2. Considering the high grazing effect by

Table 2. Phytoplankton biomass and production.

Date	Z (m)	SD (cm)	B (mg chl. a/m^2)	P (g O_2/m^2 per day)
Aug.-Sept. 1979	1.6	30-60	95	7.5-14.7
Mar.-Apr. 1980	4.0	100-130	59	3.8-8.6
July-Aug. 1982	3.5	50-80	158	4.5-6.5

Note: Z, mean water depth; SD, secchi disc reading; B, chlorophyll a (chl.a) concentration; P, oxygen production.

zooplankton and the high population densities of the indigenous phytoplanktivorous fish (A. melettinus), it appears that this resource base is delicate. Stunting populations, most likely a result of food limitation as a result of intraspecific competition has been recorded.

This leads to the question of population control. Originally, it was considered that the drawdown regime might strongly influence the breeding success in reservoirs. Recent studies by Amarasighe and Upasena (1988) on the depth distribution of O. mossambicus nests contradict this assumption.

There is, however, no doubt that populations of O. mossambicus are exposed to heavy predation both by small piscivorous fish and by fish-eating birds. A strong predation effect on the fry is exerted by several species of fish, e.g., Rasbora daniconius, Glossogobius giuris, and Barbus sarana.

A final point to be discussed is the impact of fish-eating birds, which are considered to be powerful competitors to man in the tropics. Therefore, our working program included a "cormorant" compartment (Winkler 1983); 27 species of fish-eating birds were recognized, of which only a few play a significant role.

The main questions to be addressed are whether they are competitors for fish to man or whether they are a driving force in nutrient recycling. To clarify these questions, studies have to be carried out on the direct effect of bird predation on the population density and structure of fish and the effects of birds on the nutrient budget and nutrient flow.

Cormorants are represented by three species: the large cormorant (Phalacrocorax carbo sinensis), the Indian shag (P. fuscicollis), and the little cormorant (P. niger). These three species differ in size, diving depth, and fishing distance from the shore. Little cormorants hunt within the littoral zone; the two larger species also hunt on the open lake (see Fig. 3). The average prey size of the three species and the maximal numbers of birds observed at the lake are given in Table 3.

Phalacrocorax fuscicollis clearly is the most numerous species having the heaviest impact. Winkler (1983) calculated a mean daily fish consumption of 696 kg fish (254 or 150 ka/ha per year), which

Table 3. Ecosystem impacts of cormorants (Phalacrocorax).

	Size (g/fresh weight)	Fish prey size (length, mm)	Fish eaten (g/fresh weight/day)	Max. population on Parakrama Samudra
P. niger	475	30-70	96	1850
P. fuscicollis	930	60-120	171	13700
P. carbo sinensis	1200	130	345	102

roughly converts to 5 mg C/m^2 per day. It is of interest to note that this value approximately corresponds to the daily catch of the commercial fisheries. The main question in this respects is which size classes (Table 3) and which species of fish are taken as prey. Only very restricted information is available on the diets of cormorants in PS.

Based on data of preferred fish sizes, foraging behaviour, feeding flocks, and habitat requirements, as well as on the abundance and distribution of fish in the lake, it appears that specifically A. melettinus and the young stages of O. mossambicus and Barbus are hunted. It has been suggested that moderate natural predation on small size classes may help to achieve sustained economic yield of the larger ones by reducing the intraspecific competition, e.g., for food (Winkler 1983). A general positive effect of cormorants can be expected from short-circuiting the nutrient flow, i.e., by making available the nutrients locked away within noncommerical fish (Bowmaker 1963). Fittkau (1970) arrived at a similar conclusion by considering Amazonian ecosystems ("more predators on fish, the more fish!"). It appears that cormorants at conditions of the shallow lowland reservoirs have, in sum, a positive effect by short-circuiting the nutrient flow and by reducing intraspecific competition in "phytoplankton-dependent" species!

Conclusions

The PS study exemplifies which type of recommendations for fisheries management can be derived from an ecosystem-oriented study. Two examples are made.

First, with regard to "unfilled niches," a detailed analysis of the resource base in combination with the trophic requirements of indigenous species allows predictions on the possible success of exotics. In PS, and similar, highly productive reservoirs in Sri Lanka, most resources, especially, the phytoplankton, the zoobenthos, and the littoral aufwuchs communities, appear to be used by strong competitors. We would predict that the introduction of exotics dependent on these resources (e.g., Cyprinus carpio, Tilapia rendalli) are bound to be unsuccessful! Considering the high population densities of small fish, the introduction of larger piscivores should be taken into consideration from a fisheries point of view. One has to bear in mind, however, that piscivorous fish often are "keystone" predators with a "top-down" effect cascading through the whole food chain (e.g., Bennadorf 1986). The present situation in Lake Victoria, for example, where the introduction of the Nile perch (*Lates niloticus*) has strongly influenced the fisheries and has led to an endangerment of the local cichlids, gives a clear warning for unconsidered management decisions.

Our considerations refer to just one type of Sri Lankan reservoir (shallow, lowland reservoirs, with extensive littoral zones and high population densities of fish-eating birds). The newly constructed, deep, upland reservoirs with steeper littoral slopes and generally lower productivity present a totally different situation. The question of "unfilled niches" will be more appropriate. A detailed study on the resource base before experimenting in a scientifically unsound way with the introduction of exotics is of great importance.

Second, there is the exploitation of unconventional resources (De Silva and Sirisena 1987). The high productivity of small fish species has been demonstrated. The problems with their exploitation concerns their seasonality and the type of gear to be used without harming the populations of other species.

Small zooplanktivores like *E. fluviatilis* might be harvestable with large pelagic lift nets (like the Limnothrissa in Lake Kariba). Untapped resources, not efficiently used by the traditional gill-net fisheries, also occur in the form of catfish (Heteropneustes) and eel populations (Wickstrom and Enderlain 1987).

By changing the fisheries practice, however, an important aspect that must be considered is the effect a certain species exerts on its environment.

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RESERVOIR FISHERIES MANAGEMENT AND ENVIRONMENTAL IMPACTS: WESTERN EXPERIENCES

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Abstract *Reservoir fisheries in North America are mainly dependent on naturally reproducing populations. The major economic value of these fisheries is derived from recreational use. Reservoir construction and operation can affect fish populations by restricting fish passage, affecting reproductive success, affecting downstream waters, affecting aquatic productivity, and enhancing contaminant bioaccumulation. River-diversion projects have additional impacts. Potential yields from reservoirs can be estimated from physical and climatic variables, nutrient levels, or rates of primary production. Regulations controlling fish size, length of open season, entry to the fishery, and bag limits are commonly used. Fish stocking and control of water drawdown are often attempted to enhance yields. Further research is required in many areas including the stocking effects, recruitment relationships, and the effects of harvest regulations.*

There are about 1650 large reservoirs (>200 ha) in the United States with a total surface area of 4.1 x 10^6 ha. In Canada, which has many natural lakes, there are fewer reservoirs (total area, about 200,000 ha). Most North American reservoirs support recreational fisheries. In 1980, recreational fishing on reservoirs amounted to 22% (150 x 10^6 work days) of all freshwater fishing and generated total retail expenditures of USD 3 billion (Hall 1985). It is projected that by the year 2000 reservoirs will provide 300 x 10^6 angler days/year and, because few new reservoirs are being planned or constructed, most of the fishing pressure will be on existing reservoirs. In contrast to reservoirs fisheries in Asia, Africa, and South America, the economic value of recreational fisheries on most North American reservoirs far exceeds that of commercial fisheries.

In the United States, most reservoir fish are of the warm-water varieties (Centrarchidae); however, in Canada, cold-water species dominate (Percidae and Salmonidae). Most fish populations in North American reservoirs reproduce naturally, although some stocking is performed. The advantages and disadvantages of stocking are discussed later.

Fisheries concerns have generally been secondary to the primary reason for reservoir construction; therefore, the design and operation criteria for reservoirs do not always favour the development of productive, exploitable fish populations. Primary uses include hydroelectric power production, flood control, irrigation, navigation, and recreation. This paper reviews the environmental impacts of reservoirs on fisheries, outlines current management practices and research objectives, and comments on the future of reservoir fisheries in North America.

Environmental Impacts

Fish Passage

Without provision for fish passage, dams created as part of reservoir projects can prevent the movement of migratory fish, whether anadromous, catadromous, or fish that migrate entirely within freshwaters. These problems are especially noticeable with anadromous Pacific salmon. Dams without fish-passage facilities on the Fraser and Columbia rivers have blocked major upstream runs of salmon (Ebel et al. 1987; Northcote and Larkin 1987). Even where fish-passage facilities are planned, it is often difficult to design ladders that effectively attract fish and allow them to pass without delay. Migratory fish can be on relatively inflexible energy and time budgets and may be quite intolerant of delays (Northcote and Larkin 1987).

Reservoir Productivity

Many reservoirs evolve through stages of productivity called "trophic surges" and "trophic depressions" (Rzoska 1966). A trophic surge often occurs soon after reservoir creation and is a period of relatively high productivity caused by the utilization of nutrients and organic material from flooded soils and vegetation. When these sources are depleted, reservoirs can enter a trophic-depression phase characterized by much lower rates of production. Growth rates, abundance, and production of fish often follow the general pattern of being high after reservoir creation and lower thereafter. The trophic-surge phase can be greatly modified by additional factors, especially by increases in suspended solids from unstable shores, which can reduce light penetration and limit primary production (Hecky et al. 1984). In addition to factors affecting natural lakes, such as climate, water depth, and nutrient supply, the long-term productivity of a reservoir will depend on factors unique to reservoirs, especially annual variations in water level. Drawdown can severely limit littoral production, and fish populations in reservoirs with pronounced annual drawdown often become highly dependent on pelagic productivity (Nilsson 1973).

Reproduction Opportunities

The fish community of a reservoir is strongly influenced by changes in the spawning habitat. In general, fish communities in reservoirs are transformed from those adapted to riverine conditions to those adapted to lacustrine conditions (Beckman and Elrod 1971). Reproduction in reservoirs can be strongly affected by drawdown. Decreasing water levels during spawning and egg incubation lead to egg atresia, increased egg mortality, and weak year classes for many species (Nelson 1968; June 1970). Alternatively, flooding during the spawning season can significantly increase recruitment of some species. This was demonstrated for a population of white crappie

(Pomoxis annularus) in a Kansas reservoir (Beam 1983). Shore erosion may increase sedimentation on incubating eggs and limit the reproductive success of other species (Hassler 1970; Fudge and Bodaly 1984).

Bioaccumulation of Contaminants

Fish with high levels of methyl mercury occur in may reservoirs (Bodaly et al. 1984; Boucher et al. 1985). This phenomenon is caused by the increased bacterial methylation of mercury in flooded soils (Ramlal et al. 1987). In subarctic reservoirs, mercury levels in predatory fish remain elevated for at least a decade (Bodaly et al. 1984). Similar data do not exist for temperate and tropical reservoirs. The possibility of bioaccumulation of other metals or contaminants as a result of reservoir creation has not been examined.

Downstream Effects

Water released from reservoirs to downstream areas can severely affect fish populations. Lowered water temperatures and lowered dissolved oxygen concentrations are common in discharged water drawn from in the hypolimnia in reservoirs (Craig and Kemper 1987; Voigtlander and Poppe 1987). Epilimnetic releases can result in temperatures that are too high for downstream, cool-water species (Northcote and Larkin 1987; Voigtlander and Poppe 1987). The annual pattern of releases can also have pronounced downstream effects, especially in areas that are dependent on annual flooding for maintenance of channels, vegetation communities, and general productivity (e.g., deltas) (Rosenberg et al. 1987).

Effects of Diversions

Reservoir projects are often accompanied by river diversions. River diversions can result in the exchange of fish and fish parasites between watersheds; some of these species can be undesirable (Lindsey 1957). Diversions cause drastic decreases in fish habitat in the watershed from which the water is diverted as well as flooding and instability in the watersheds that receive the diverted waters (Hecky et al. 1984).

Management Practices

To successfully manage a reservoir fishery, regular measurements of population size, age and size structure, maturation, reproduction, growth rates, and feeding habits of the major species are necessary. Electrofishing, trap netting, or trawls are usually used for assessments. Rotenone poisoning has been utilized to determine the total fish biomass. A well-structured creel census can also provide valuable information for the manager. Estimates of fish standing crop in reservoirs can be related to climate, reservoir area, age, depth, relative shoreline length, water-level fluctuations, water-exchange rate, and water chemistry. Another indicator of productivity is the morphoedaphic index: MEI = $TDE/\overline{Z}$, where TDS is total dissolved solids and $\overline{Z}$ is the mean depth (Ryder 1965). Schlesinger and Regier (1983) related MEI to sustainable yields of walleye (Stizostedion vitreum) from 23 lakes in Canada and the northern United States. Their model accounted for over 69% of the variation in yield. Other researchers have used factors such as primary productivity (Oglesby 1977) or total biological phosphorus (Hanson and Leggett 1982) as predictors of fish yields.

The manager needs to measure the amount of recreational use and the economic value of this use. A benefit/cost analysis can then be compared with that of other water resource uses. The analysis should include fishing tackle, other equipment, travel, meals, accommodation, and fees. The social benefits of the fishery should also be considered.

With these data, the manager can attempt to provide an optimal fishery. As previously stated, reservoirs are difficult to manage because of their multiple uses and sequence of varying productivity. In the United States, there are further problems associated with water property rights and ownership, especially where reservoirs cross state boundaries. Fishery managers are confined to activities that will not affect downstream water users. The main methods of controlling the fishery include size limits, season controls, limited entry, quotas (bag limits), and licences. Closed seasons, closed areas, and shortened seasons can protect fishes during critical periods in their life cycles such as spawning periods.

Size limits are intended to increase the catch of larger fish and protect potential spawners. In many cases, however, an increased size limit has resulted in a decreased yield of larger fish and an increased population of younger, smaller fish; this often results in slower growth rates. Fishery managers are now considering protecting a specific size group of a species, often called "slot size limits" (Brousseau and Armstrong 1987). Problems arise in encouraging anglers to remove small fish.

Stocking is a common management practice in reservoirs. There are three types of stocking. Firstly, stocking can be introductory; i.e., the stocked species is new in the habitat. Secondly, where natural reproduction is limited or absent, stocking can be used to maintain a species. Thirdly, stocking can supplement the natural reproduction of existing fish. Laarman (1978) investigated the success of stocking walleye into 125 water bodies over the last 100 years. The success rate was 48% in introductory stocking, 32% in maintenance stocking, and only 5% in supplementary stocking. Stocking of hatchery-reared and other nonnative fish can dilute the gene pool of the indigenous population if the fish are introduced in large numbers. Chilcote et al. (1986) found that hatchery-reared steelhead trout (*Salmo gairdneri*) were less successful at reproducing naturally than wild fish. In their study, however, 62% of the naturally produced summer-run smolts were offspring of hatchery spawners because of the larger numbers of hatchery-reared fish that were stocked. Thus, supplementary stocking is usually unsuccessful and the practice can threaten the genetic integrity of a wild population by lowering its genetic fitness.

Research Needs and the Future

The results of a recent survey of reservoir managers in Canada and the United States on future research requirements were recorded by Hall (1985). Future research areas include predator-prey interactions, optimum stocking procedures, factors affecting recruitment, and the impact of harvest regulations on individual fish species and population balance. Other areas of concern include water quality - fish interactions, the impacts of reservoir drawdowns and water-level fluctuations, the effects of management techniques such as stocking and habitat improvement, the development of a data base on standing crops and harvests, and the development of models as a basis for reservoir management. With long-term data, refined techniques such as time-series analysis can potentially be applied. Simulation models are useful in predicting future events; however, their accuracy is dependent on modeling processes, the quality and quantity of the input variables, and the interactions between variables.

In North America, the future of reservoir fisheries depends on information exchange between users and manager, on a critical assessment of current practices for managing reservoir fisheries (new ideas and approaches), and on the role of the fishery manager relative to reservoir planning operations and other recreational users (Summerfelt 1986).

Conclusions

The problems facing fisheries managers of reservoirs in North America, both in terms of environmental impacts and the present technologies at their disposal, have been outlined. The successful management of inland fisheries depends on an understanding of biological, economic, and social factors, the order being an indicator of relative importance. Fishery science that has evolved over the last hundred years in developed countries has been mainly based on ocean fisheries and normally on single-species stocks. Many of the principles derived from ocean fisheries have been applied, perhaps without much vaidity, to inland waters. This has also been the case for lake and reservoir fisheries in developing countries (Oglesby 1985). Although the uses of reservoir fisheries in developed (recreational fisheries) and developing (food fisheries) countries are different, the future approach to their management should be similar. Data should be collected that can be used to predict optimum rather than maximum sustainable yields from the reservoir that benefit the user in socioeconomic terms. In most cases, reservoir fisheries are rather low in priority compared with other uses. Predictive capabilities of any fishery yield model must include input for natural perturbations such as water drawdown.

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ABSTRACTS

The Concept of Reservoir Fisheries Management

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Reservoirs are open-water ecosystems, and the most practical and efficient fisheries exploitation strategy to be developed is the so-called "self-sustaining" pattern. This is characterized by a balance between the carrying capacity of the reservoir and its utilization pressure. Fisheries management of reservoirs need to cover aspects of reservoir zone (zonation) management, fisheries exploitation patterns, and reservoir conservation policies. Reservoir zone management is a new concept that is being developed in some Indonesian reservoirs and is showing positive impact on all reservoir uses, including fisheries management. The organizational structure of reservoir fisheries management has received little attention in the region. A more concentrated effort is needed to bring about an effective coordination between all reservoir users.

Fisheries Management Strategies in Two Reservoirs in the Philippines

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Fisheries management strategies for two reservoirs in the Philippines with contrasting management purposes are discussed. Caliraya Reservoir, in the southern province of Laguna, was constructed in 1939 for hydroelectric power generation. It has a surface area of 1160 ha. Nile tilapia (Tilapia nilotica) represents about 76% of the fish catch; largemouth bass (Micropterus salmoides), 12%; common carp (Cyprinus carpio), 7%; and mudfish (Ophicephalus striatus), 5%. Nile tilapia and common carp are stocked by the Philippine Bureau of Fisheries and Aquatic Resources to enhance the catch of about 100 fishermen. Largemouth bass is stocked for recreational fishing. Caliraya Reservoir is the only inland body of water in the Philippines where sport fishing is being promoted. Magat Reservoir was built for irrigating ricelands in northern Luzon. It is the second-largest reservoir in the Philippines, with a surface area of 4460 ha. The fisheries of this reservoir is the most productive in the country, with a total catch of 6720 t in 1986. Floating cages, with sizes ranging from 4 m x 4 m to 12 m x 14 m, are used for commercial cage culture of Nile tilapia. By 1986, 785 fish cage units, with a total area of 56.28 ha, were being operated by 212 fish farmers.

DISCUSSION

This session predominantly dealt with descriptions of reservoir management systems, either currently in operation or proposed, from various Asian countries including Bangladesh, India, Indonesia, the Philippines, Sri Lanka, and Thailand. There was also a review of Western experiences. The session concluded with two papers on fish pressures on ecosystems and ecosystem approaches to management. Discussion of the individual papers was wide ranging and covered five main topics:

- the aim of fisheries management in Asia (maximum sustainable yield or optimum yield?);
- importance of collecting length-frequency data;
- government-fishermen communications;
- significance of prepared plans using the available information to implement immediate management strategies; and
- possibility of predicting fish yields using sample parameters.

Specifically, the delegates were asked to consider recommendations for fisheries management, classification, and procedures for different fisheries; regulations (scientific, economic, and social); and yield predictability.

Stocking practices in most countries are not well organized. In Indonesia, there is no scientific basis for deciding on empty niches in the reservoir ecosystem. Stocking is a trial-and-error practice. In India, hydrobiological studies have been carried out in a newly constructed reservoir before and after the impoundment. Closed seasons have been imposed for fishing during the spawning seasons of commercially important fish species. Stocking was done for controlling weeds that were developed as a result of usual postimpoundment eutrophication. Stocking practices in Thailand are also for weed control and snail control, although the high turbidity during rainy seasons also kills submerged vegetation. In the Philippines, the high productivity in the deeper reservoirs, situated at high altitudes, was suggested to be due to the availability of shallow, inshore areas.

The paper on socioeconomics in the reservoirs of Sri Lanka was considered to be an important study. In Sri Lankan reservoirs, the fishermen fall into two categories: unorganized and organized. As such, there should be active government mediation to form societies, especially in the case of the unorganized fishermen. Academic education level among fishermen is not as important an aspect in the management of Sri Lankan reservoirs as is the fishermen's experience. The part-time fishermen in these reservoirs are farmers who learned fishing from the migrant fishermen of the coastal areas.

In Bangladesh, floodplains are stocked with fingerlings by the government once each year. Nevertheless, the basis for determining stocking rates has not been properly established. In Bangladesh reservoirs, there are no conflicts between different purposes, except in the floodplains where there are conflicts between rice and fish. From the evidence of ecosystm studies in Parakrama Samudra in Sri Lanka, the energy budget of the ecosystem and biomanipulation have been shown to be important aspects of reservoir fisheries management.

The experience in reservoir fisheries management in North America can be utilized to a certain extent to manage the fisheries in Asian reservoirs. It should be noted that the objectives of the fisheries management in the two regions are quite different. In Asia, reservoir fisheries is practiced primarily to provide protein for human consumption. In North America, however, reservoir fisheries are primarily used for recreational purposes. Nevertheless, some aspects of the North American management strategy, such as relying on natural recruitment and cooperation between fishermen and managers, are important for Asian reservoir fisheries management.

General Discussion

The need to analyze niche availability before filling vacant niches was highlighted during the final discussion of this session. Quantitative models of food availability, population estimates (probably using hydroacoustics), energy-flow models, etc., would be useful in planning stocking programs as well as determining exploitation levels. In irrigation and hydroelectric reservoirs, heavy drawdown and predation on fish are important aspects. In the reservoir with heavy predation by birds, the stocking size (if fish are stocked) should be determined by the vulnerability to predation.

Any reservoir fisheries management strategy should be based upon scientific studies. Subsequently, economic and social aspects should be taken into consideration. For example, in Parakrama Samudra, there are hardly any empty niches for phytoplankton feeders and the zooplankton populations are low. Exploiting untapped fishery resources such as minor cyprinids in Sri Lanka would be helpful in increasing fish production. The acceptance by consumers of trash fish should be taken into consideration when exploiting untapped resources.

Managing fisheries in multipurpose reservoirs has certain constraints. In irrigation reservoirs, the fisheries industry is secondary. Fisheries management should be done within the framework of irrigational requirements. Possibilities of yield prediction using empirical indices such as water-level fluctuations and productivity-related parameters should be attempted as initial management procedures for places where there are no reliable data.

As the discussion for this session wrapped up, the delegates attempted to classify reservoirs (perennial) in the different countries based on the nature of the fish communities. The following parameters were used to classify the reservoirs: stocking practiced?; ratio of exotic to indigenous species; feeding habits of fish (herbivore, carnivore, planktivore, omnivore); fishing effort (light, moderate, heavy, variable); regulations (fishing gear, seasons, etc.); and size of reservoir.

Session V

Culture

CAGE-CULTURE PRACTICES IN SRI LANKAN RESERVOIRS

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Abstract *Culture of Oreochromis niloticus in cages was carried out in the Udawalawe Reservoir (06°20' N, 80°50' E) to ascertain in lower stock density limit for cage culture for that species, to compare the results with previous cage culture trials involving O. niloticus at a stocking density of 400 fish/m^3, and to compare with farmer-managed extension trials at the same stocking density. The net cages were 2.0 m by 2.0 m by 1.25 m and were suspended by a floating square bamboo frame. Oreochromis niloticus were stocked in cages at a stocking density of 50 to 200 fish/m^3. The fish were fed six times daily at 3% body weight with a pelleted diet containing 20% protein. The trials lasted 6 months and samples were weighed every 5th week to evaluate growth. Results showed that, a stocking density of 300 fish/m^3, when O. niloticus is subjected to a two-stage culture process, comparable results (in terms of final biomass per cage) to those obtained with the same species at a stocking density of 400 fish/m^3 are obtained. The mean final weight, however, was significantly higher at 200 fish/m^3 ($P < 0.05$). Although the mean weight at harvest of O. niloticus stocked at 50 fish/m^3 was higher, the final biomass per cage was considerably lower. Finally, the farmer-managed extension trials also produced a comparable final mean weight as that obtained at a stocking density of 400 fish/m^3 from previous cage culture trails ($P > 0.05$).*

The total inland fish production from all sectors in Sri Lanka in 1985 was 35,500 t (Sri Lanka 1985). Of this production, capture fisheries from perennial tanks accounted for about 90% (31,950 t). This has increased from 16,000 t in 1976. However, because the fish production from perennial tanks cannot be expected to increase indefinitely, being governed by the maximum carrying capacity of each tank, the Ministry of Fisheries has begun emphasizing aquaculture practices in Sri Lanka. Three activities for the development and extension of aquaculture in rural Sri Lanka have been undertaken by the Ministry of Fisheries: seasonal tanks aquaculture program; pond fish culture program; and cage and pen culture of fish, (a project funded by the International Development Research Centre, Canada).

Preliminary Work on Cage Culture

The preliminary trials on cage culture were conducted at the Udawalawe Reservoir (06°20' N, 80°50' E), which was the main experimental site. Various species, e.g., grass carp (*Ctenopharyngodon idella*), silver carp (*Hypophthalamichthys molitrix*), rohu (*Labeo rohita*), and *Oreochromis niloticus*, were tested (Fig. 1).

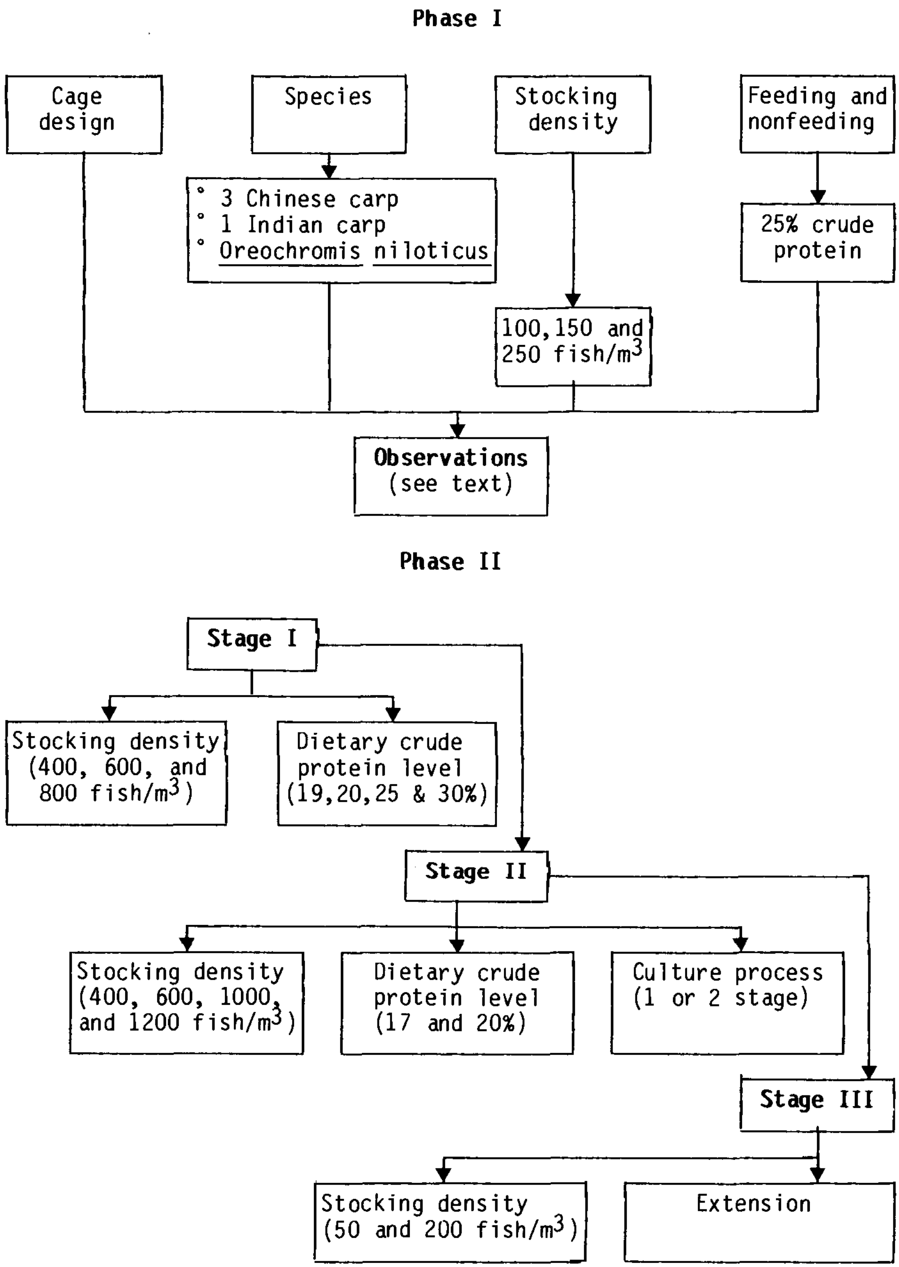

Fig. 1. Sequence of research trials on cage culture of *Oreochromis niloticus* in the Udawalawe Reservoir.

Of these species, only O. niloticus was successful because of its fast growth rate, good reaction to supplementary feeds, and resistance to disease under stressful conditions. The growth of Chinese and Indian carps was poor because of low plankton productivity, the small initial fingerlings, the inadequacy of the supplementary feeds, and the high incidence of disease. Other observations during phase I trials included the following: feed wastage at a feeding rate of 10% body weight; at the various stocking densities tested, no significant differences in final mean weight; and a higher final biomass at a stocking density of 250 fish/m^2 (Wannigama et al. 1982).

Results of Phase II Trials

Trials on O. niloticus gave the following results (Muthukumurana and Weerakoon 1986). Of the stocking densities tested (400-1200 fish/m^3), 400 fish/m^3 produced the highest average body weight (150-175 g). The final biomass of O. niloticus subjected to a two-stage culture process (Fig. 1) was highest at a stocking density of 400 fish/m^3. This final biomass ranged from 280 to 330 kg/cage (56-66 kg/m^3). The feed-conversion rate (FCR) ranged from 2.5 to 2.8 at a stocking density of 400 fish/m^3, with a diet containing 20% crude protein.

Low-Density, Two-Stage Culture

The final trials with O. niloticus were directed at studying the growth and production of O. niloticus at two low stocking densities (50 and 200 fish/m^3) to determine the stocking minimum for O. niloticus in cages and at studying farmer-managed extension of cage culture technology.

Methodology

The same materials and methodology used in previous cage culture trials were used for these trials (Wannigama and Weerakoon 1982; Wannigama et al. 1983). The cage frames (3.0 m x 3.0 m) were made of bamboo. The net cages were constructed with 12-ply, 10-mm mesh netting and the dimensions of each cage was 2.0 m x 2.0 m x 1.25 m. The net cages were covered on top to prevent prèdation by birds. Oreochromis niloticus fingerlings ranged from 23 to 25 g. Stocked at 50 fish/m^3, the fingerlings were subjected to one-stage culture (i.e., no thinning). The culture period was 180 days. Fingerlings from 23 to 25 g stocked at 200 fish/m^3 were subjected to both one- and two-stage culture in separate cages (Fig. 2).

During culturing, the fish's diet contained 20% crude protein (Table 1). The fish were fed six times daily with the daily quantity of feed not exceeding 3% of body weight. All the trials were carried out in duplicate. Cage culture of O. niloticus as described but with only one stocking density (400 fish/m^3) was carried out by selected farmers living next to the Udawalawe Reservoir. The aquaculturists at the fisheries stations in Udawalawe provided technical advice to these farmers.

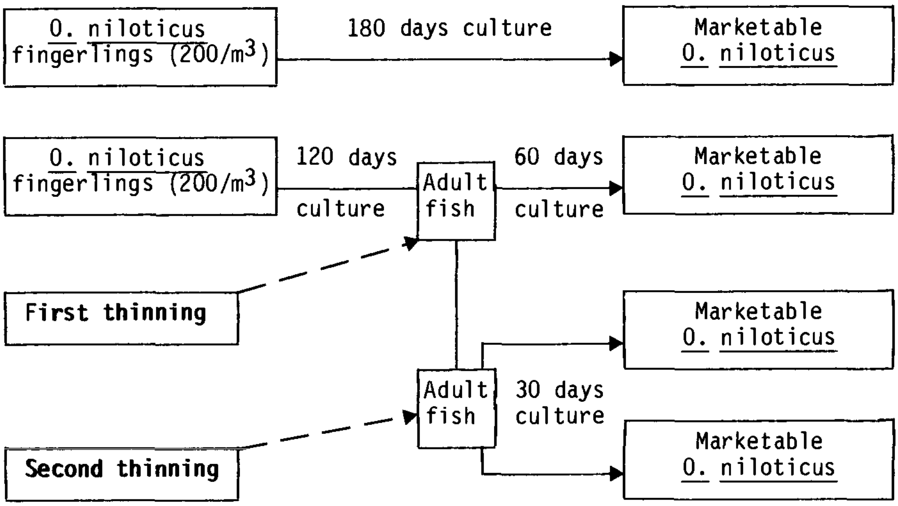

Fig. 2. One- and two-stage culture of *O. niloticus* fingerlings.

Results

The average weight at harvest was highest at a stocking density of 50 fish/m^3 (Table 2). Two-stage thinning of *O. niloticus* at a stocking density of 200 fish/m^3 produced about the same average body weight per fish at harvest. The FCRs were 2.0 and 2.5 for 50 and 200 fish/m^3, respectively. One-stage culture (no thinning) of *O. niloticus* at 200 fish/m^3 produced a comparatively low average body weight per fish at harvest. In addition, the FCR was comparatively high in one-stage culture. The survival rate in all cases was over 90% (Table 2); therefore, *O. niloticus* is able to adapt to the stressful conditions in the cages. The final biomass was lowest at a stocking density of 50 fish/m^3 (Table 2). The final biomass at 200 fish/m^3 ranged from 142 to 224 kg, which is significantly less than the 332 kg obtained at 400 fish/m^3 in previous cage culture trials (Table 3).

The average weight per fish at harvest from two farmer-managed extension trials was lower than that obtained in research trials (Table 3). In these two cases, however, the initial stocking size per

Table 1. Percent composition and proximate analysis of diet.

Ingredient	%	Component	%
Fish meal	7.0	Protein	20.0
Rice polish	30.8	Fats	5.8
Coconut meal	50.0	Crude fibre	7.8
Starch	12.0	Moisture	11.2
Vitamin premix	0.2		

Table 2. Comparative data on *Oreochromis niloticus* at stocking densities of 50 to 200 fish/m^3 subjected to one- and two-stage culture.

	One-stage culture		Two-stage culture	
Stocking density				
Fish/m^3	50	200	200	200
Fish/cage	250	1000	1000	1000
Initial weight per fish (g)	14.5	24.3	24.8	24.8
Initial biomass (kg)	6.5	24.0	24.5	24.0
Final weight per fish (g)	256	156	225.4[a]	238.2[b]
Final biomass (kg)	64	142	215.0	224.0
Duration of culture (days)	180	180	180	180
Feed-conversion rate (FCR)	2.0	2.5	2.1	2.0
Specific growth rate (SGR)	16.6	5.3	8.2	8.6
Survival rate (%)	94	91	92	95

[a]Final weight per fish after thinning at 120 days.
[b]Final weight per fish after the first thinning at 120 days and the second thinning at 150 days.

Table 3. Comparative data on cage culture of *Oreochromis niloticus* in farmer-managed extension trials and previous experimental trials at Udawalawe Reservoir.

	FM[a]			
	1	2	3	PT[b]
Stocking density				
Fish/m^3	400	400	400	400
Fish/cage	2000	2000	2000	2000
Initial weight per fish (g)	24.5	12.3	14.0	30.7
Initial biomass (kg)	47.6	24.0	28.0	61.4
Final weight per fish (g)	199	142	154	175
Final biomass (kg)	206	150	194	332
Biomass/year (six cages)	2900	1800	2300	3900
Duration of culture (days)	180	180	180	180
Specific growth rate (SGR)	7.1	10.2	12.8	4.7
Feed-conversion rate (FCR)	2.5	3.2	3.0	2.5
Survival rate (%)	60	50	63	94.7

[a]FM, farmer managed.
[b]PT, previous trials (Muthukumarana and Weerakoon 1986).

fish varied from 12 to 14 g, which was lower than the initial stocking size in the research trails. The FCR in the farmer-managed trials ranged from 2.5 to 3.2 (Table 3).

Discussion

The results of this study are comparable with those of Coche (1977) and Campbell (1978). For *O. niloticus* cage culture, a two-stage process or a culture cycle, in which thinning is carried out in one or two stages, is best. Campbell (1988) developed a similar system for producing calibrated *O. niloticus* fingerlings for stocking in commercial cage culture. By resorting to two-stage culture, the farmer is assured of a monthly harvest of marketable fish, thereby ensuring year-round culture operation (Fig. 3).

Trials with *O. niloticus* show that the final biomass obtained at a stocking density of 200 fish/m^3 could be comparable with that obtained at a stocking density of 400 fish/m^3. This study also suggests that 200 fish/m^3 is the minimum functional stocking density. Below this, the final biomass at harvest decreases.

In the farmer-managed extension trials, the survival rate was between 50 and 60% (Table 3). In spite of this relatively low rate, no diseases were observed by the aquaculturists during their regular inspections. Cutting of nets by otters has been offered as a possible explanation by the farmers. Because the losses occurred 1 month before harvesting, poaching is another possible explanation.

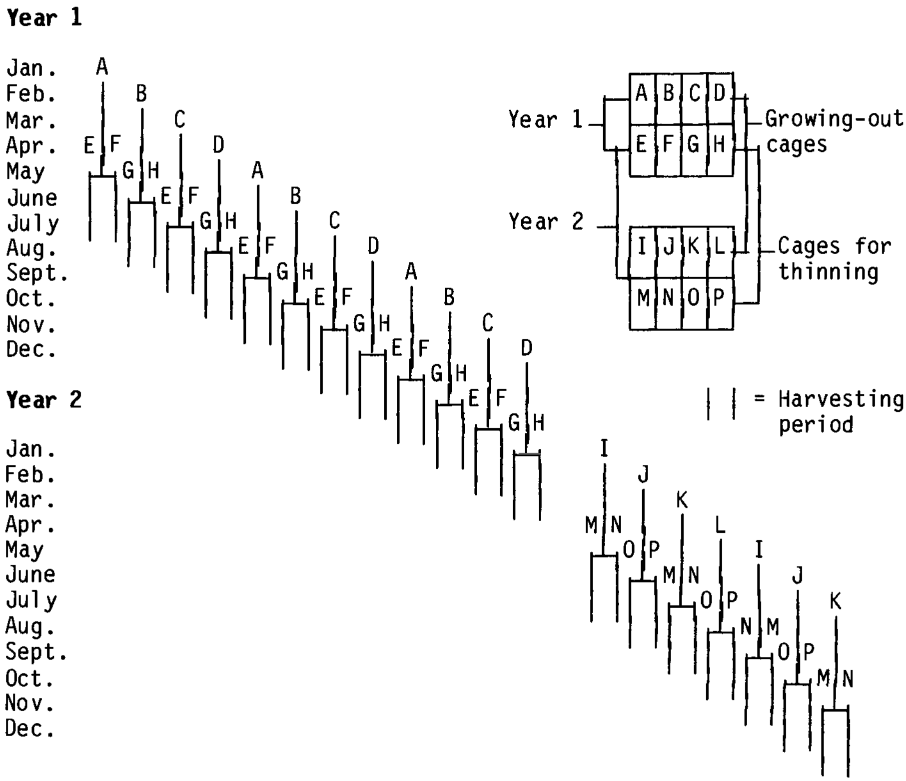

Fig. 3. Time span for two-stage production process with monthly harvesting.

Potential of Cage Culture

According to an economic analysis of cage culture in Sri Lanka (Atapattu 1986), it is economically feasible to culture O. niloticus in cages at a stocking density of 200 fish/m^3 provided a two-stage culture process is used. An annual fish production of 3500-4000 kg could be achieved with nine 5-m^3 net cages. A total monthly profit ranging from USD 280 to 400 could be obtained with judicious management practices. Because of the initially high capital investment required, the Ministry of Fisheries has initiated steps to introduce a subsidy scheme for cage culture to popularize this fom of aquaculture among the rural population.

Acknowledgments

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THE PRINCIPLES AND STRATEGIES OF FISH CULTURE IN CHINESE RESERVOIRS

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Abstract *This paper introduces the principles and methodologies used in Chinese reservoir fish culture. The original characteristic and central core of reservoir fish culture in China is polyspecific (integrated) stocking, mainly of bighead and silver carp (60-90% of production). Models have been developed to help managers assess productivity. Techniques of determining the optimum stocking rate and species proportions, controlling predators and low-value fish, preventing fish escape, and managing fish are described.*

In China, reservoir fish culture began at the Dongjianhu Reservoir, which was built in 744 during the Tang Dynasty. However, reservoir fish culture has been productive for only about 30 years. Before 1949, there were several reservoirs in China; however, besides a little fishing, there was almost no fish culture. After 1949, as water-conservation facilities were developed, a lot of reservoirs were constructed. Reservoir fisheries developed rapidly and now are an important component of freshwater fish culture in China.

Ecological Basis of Reservoir Fish Culture

Efficient Use of Resources

Reservoirs contain both introduced and native organic materials. In the first years of impoundment, introduced materials (plants, detritus, bacteria) are more important. Several years later, native organic materials become slightly more important.

The circulation of energy and matter is open in reservoir ecosystems. A considerable portion of the nutrient matter input from the catchment area via runoff sinks to the bottom of the reservoir. The dissolved nutrients immediately become involved in the aquatic productive process. Because of the frequent exchange and discharge of water, nutrients, food organisms, and even fish are easily lost.

Aquatic production processes result from the cooperative actions of three ecosystems: the body of water, the catchment area, and the drying and immersing replacement area. Aquatic production takes place in the water, but processing and fish productivity are affected seriously by the water-land replacement system (drying and immersing replacement area) and the catchment area ecosystem. Proper vegetation and good soil fertility in the catchment area are essential to ensure high-quality introduced matter (plants, detritus, bacteria, nitrogen, phosphorus, silicon) and, therefore, to ensure food availability. The annual or seasonal dynamics of the drying and immersing replacement area caused by monsoons and water discharge regulation adversely affects plant and benthos growth and the propagation of fish. Therefore, the catchment area ecosystem and the drying and immersing replacement area must be managed effectively to ensure that nutrients flow steadily into the reservoir.

Increasing Trophic Efficiency

One of the basic aims of fish culture is to optimize biological energy transfer by shortening the food chain. Bighead (*Aristichthys nobilis*) and silver carp (*Hypophthalmichthys molitrix*), both planktivorous fish and in the first or second trophic level, are commonly used as the principal species in fish culture reservoirs in China because of their high food-conversion rate and fast growth. Thus, 60 to 90% of final production depends on the second-third link of the food chain. Benthophagous or piscivorous fish occupy the fourth to sixth tropic level. Because the energy-conversion efficiency of each link is about 10%, the biological conversion efficiency of the first pattern (silver carp and bighead) is 10-100 times higher than that of the second pattern. Therefore, reservoirs in which bighead and silver carp dominate give the highest yields.

Because of the large surface area, great variation in depth, presence of still and running water, various food sources, etc., the reservoir is appropriate to fish with different habitat requirements. More than 100 fish species have been recorded in some Chinese reservoirs. Therefore, most reservoirs not only stock bighead and silver carp, but also stock omnivorous, herbivorous, benthophagous, and detritivorous species. The presence of many varieties of fish ensures that the various food resources and ecological trophic niches are properly exploited.

Traditional and Innovative Practices

Reservoir fish culturing in China is strongly influenced by traditional methods; however, some innovations have recently been adopted. Major innovations include reasonable stocking rates, predator control, fish escape prevention, and fishery management.

Stocking

Selection and Proportion of Stocking Species

Stocking levels and proportions are determined by evaluating the trophic level, biological properties, productive performance, and adaptability to available food resources of each species. In Chinese reservoirs, bighead, silver carp, grass carp (*Ctenopharyngoden idella*) common carp (*Cyprinus carpio*), blunt snout bream (*Megalobrama amblycephala*), and mud carp (*Cirrhinus molitorella*) are the most commonly stocked species.

Among natural food resources, most reservoirs are rich in plankton, detritus, and bacteria. The phytoplankton biomass ranges from 0.31 to 8.05 mg/L (Li and Xu 1987). Detritus and bacteria have not yet been quantified, but it is known that they occur in considerable amounts. The production of fish supported by plants and detritus increases when nutrient and detritus inflow is increased. By choosing bighead and silver carp as the principal species, primary production can be effectively utilized, energy-conversion efficiency can be improved, and fish production can be increased.

The biomass of macrophytes and benthos is low in most reservoirs (Li and Xu 1987). Therefore, herbivorous and benthophagous fish are usually stocked to a lesser extent. In the few reversoirs with abundant benthos or macrophytes, grass carp, common carp, and crucian carp (Carassius auratus) can be stocked extensively.

If the dominant fish of the reservoir is piscivorous, fish production will be low. Therefore, piscivorous fish are not widely cultured.

Because bighead and silver carp account for a large portion of the total fish production in cultured reservoirs, proper stocking of these two species is important. For example, in the Qingshan Reservoir, when common carp was the principal species, production was low. When the major species were changed to bighead and silver carp, fish yield increased considerably. After several years of experimentation, an optimal ratio of bighead to silver carp (65:35) was established.

In most reservoirs, with respect to individual growth rates and mass production, bighead is better than silver carp. In intensive culture ponds, however, the maximum carrying capacity of silver carp is normally 4500 kg/ha (Li 1984); the carrying capacity of bighead is only 1125-1500 kg/ha. The superiority of bighead in reservoirs has attracted the attention of fish biologists, and some related studies have been initiated. There are three possible reasons for this superiority: the biomass proportion of zooplankton to phytoplankton of a reservoir (1:1-3) is larger than that of a pond (1:3-5) (Li and Xu 1987); for the same size fish, the oxygen consumption of bighead is lower than that of silver carp (Liu and Chen 1975); the energy-conversion efficiency of bighead fed plankton is higher that that of silver carp (Wang and Liang 1981).

Stocking density

In general, a high stocking density is necessary for high yield (Fig. 1). However, if the stocking density exceeds a reasonable limit, yield will decline and the fish will be stunted and unsuitable for marketing. To reach a marketable size within a given period, stocking density must be kept at an optimum balanced point where the production, fish size, and crop turnover (the time from stocking of fingerlings to marketing) are all considered.

Historically, the method of deciding the stocking density and mixing ratio of bighead and silver carp was empirical, being based on an analysis of harvest. Rapid growth, indicative of an abundance of food, would dictate the need to increase the stocking density of all species or to increase the proportion of a fast-growing species in the next year. This is how stocking density was regulated every year until a balance was achieved between stocking density and growth rate. The successful combination in Qingshan Reservoir is as follows: bighead and silver carp, 1500 fish/ha, 13.2 cm total length; mixing

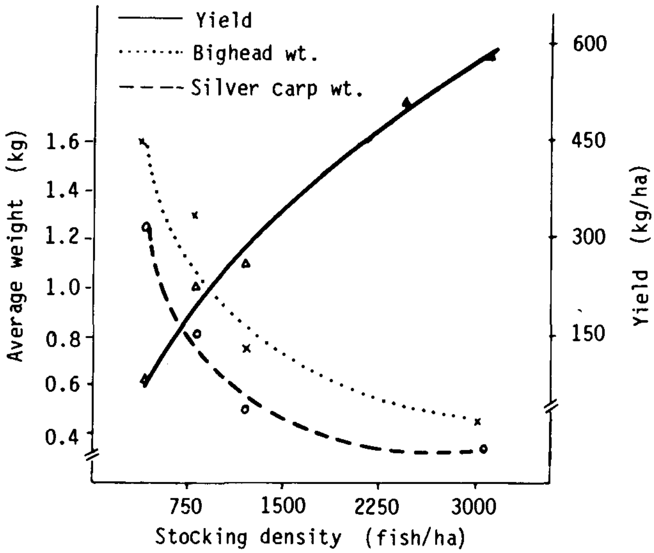

Fig. 1. Relationship between stocking density, yield, and average weight after one growing season in the Manshahe Reservoir (of bighead and silver carp).

ratio, 7:3 to 6:4. After 1 year of stocking, the body weight of bighead should exceed 0.75 kg and silver carp should be over 0.5 kg with a return (the ratio of the number of recaptured fish of marketable size to the number stocked) of about 50%.

Optimum stocking size

Stocking small fingerlings is always a major reason for poor stocking efficiency (gross yield of one species/total stocking weight of one species), low returns, and low yield. The stocking of large fingerlings has many advantages.

- Growth rate of large fingerlings is greater than that of small fingerlings (Fig. 2).

- Group weight gain and return with large fingerlings is better than with small fingerlings. In southern and eastern China, at an appropriate stocking density, 13.2-cm silver carp and bighead can be raised to a marketable size of 0.5 kg or over in one growing season. In northern and northwestern China, after two growing seasons, a 13.2-cm fingerling can be raised to 0.75 kg or more.

- Large fingerlings are able to avoid predators better. Results of several studies have indicated that fingerlings over 13 cm cannot be easily consumed by Erythroculter ilishaeformis or E. mongolicus less than 50 cm; under certain fishing pressures these predators can be kept below 50 cm (Chu et al. 1976).

- A 1-cm gap screen or a 3-cm mesh net can prevent the escape of silver carp and bighead over 13.2 cm (Li 1975).

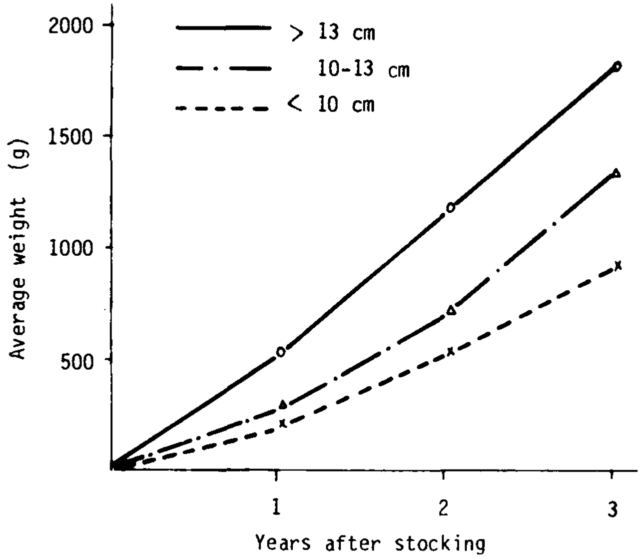

Fig. 2. Weight gain of various size bighead fingerlings in the Dongfong Reservoir.

Experiments have indicated that one 13.2-cm fingerling provides a stocking efficiency equivalent to that provided by three 10-cm fingerlings or twelve 7-cm fingerlings. It is commonly accepted that the minimum stocking size is 13.2 cm. As outlined, this minimum not only has biological basis but also is considered technologically suitable and profitable from the point of view of fry and fingerling production.

Control of Predators and Low-Value Fish

Predator fish

Common predator species in Chinese reservoirs include *Elopichthys bambusa*, *Erythroculter ilishaeformis*, *Erythroculter mongolicus*, *Parasilurus asotus*, *Siniperca chuatsi*, *Ophicephalus argus* (snakehead), *Esox reicherti* (pike), and *Opsariichthus* spp.

The harm inflicted by predator fish on reservoir fish culture is shown in two ways. First, fingerlings stocked when predators are abundant may be destroyed completely. Predator fish are mostly opportunists, willing to prey upon whatever fish are available. In stocked reservoirs, fingerlings are the major prey. This is because they have yet to develop protective structures and because they travel in schools. Second, predators depend on a long food chain, thereby lowering productivity. For example, in the Fujiaohe Reservoir (2000 ha), the yield was 420 kg/ha when the dominant fish were bighead and silver carp but declined to 22.5 kg/ha when the preditor fish *Elopichthys bambusa* because dominant. In reservoirs dominated by *E. bambusa*, the yield never exceeds 25 kg/ha.

Low-Value Fish

Common low-value fish in Chinese reservoirs include *Hemiculter leucisculus*, *Pseudolaubuca sinensisi*, *Hypseleotris swinhonis*, Pseudorasbora parva, and Gnathopogon spp. They are normally fecund, have a short life span, and are sensitive to changes in food availability. Low-value fish are usually the forage fish of predators and compete with the commercial fish for food. Their population can be controlled by fishing.

Fish Productivity Models

Two mathematical models have been developed to evaluate the potential fish productivity. This, in turn, serves as a guide to establish optimum stocking levels and proportions.

Food Biomass Evaluation

To evaluate productivity bsed on food biomass, the following equation is used:

$$\text{Fish productivity } (Y_p) = \frac{(B)(P/B)(U_f)}{K_f}$$

where B is the average yearly biomass of a certain food organism, P is the average yearly production of a certain food organism, U is the utilization ratio of food by fish, and K_f is food-conversion efficiency.

Total fish productivity can be calculated by summing the productivity of five subgroups: fish productivity supported by phytoplankton; fish productivity supported by zooplankton; fish productivity supported by macrophytes; fish productivity supported by benthos; fish productivity supported by detritus. The productivity of each subgroup can be estimated separately (He and Li 1983).

Primary Productivity Evaluation

For silver carp, fish productivity (F_h) can be calculated as follow:

$$F_h = \frac{(P_g)(f)(k)(a)(H_y)}{(E_h)(C)}$$

where P_g is the primary production (grams O_2 per square metre of water per year), f is the ratio of net primary production to gross primary production (0.78), k equals 3.51 cal/mg O_2 (1 cal = 4.19 J), a is the maximum utilization by fish of phytoplankton (0.8), C equals 1.2 kcal/g fresh fish, H_y is the relative stocking proportion of silver carp to silver carp plus bighead, and E_h is the energy-conversion efficiency of silver carp on phytoplankton (39.18). For bighead, productivity (F_a) is calculated in the same manner: H_y becomes A_r (the relative stocking proportion of bighead to bighead plus silver carp) and E_h becomes E_a (the energy-conversion efficiency of bighead on phytoplankton, 22.69).

Because f, k, a, C, E_h, and E_a are all constant, the equations for bighead and silver carp can be simplified:

$$F_h = 0.0466 H_y P_g$$

$$F_a = 0.0804 A_r P_g$$

Although these models are an effective tool for fishery managers to gain insight into productivity, their accuracy and practical value must be further tested.

Escape Prevention

The escape of fish following flood discharges over the spillway is a major threat to the reservoir fish culture. After much research and practical application, barrier nets and electric barriers have been designed, constructed, and operated extensively with positive results.

Fish Management

Fishing is not only a harvesting method but also a method of regulating the fish community and controlling the size and age composition of the population. Yield can be estimated by the following formula:

Yield = stocking density x return rate x fingerling size

For farming a reservoir, the return rate can be estimated empirically. Removal size depends on market value, turnover rate, planned yield, and expected income. The minimum acceptable size is commonly 0.75 kg for bighead, 0.5 kg for silver carp and common carp, 1 kg for grass carp, and 0.25 kg for crucian carp. There are three types of turnover rate: 1, 2, and several years (Fig. 3). The choice of turnover rate depends on geographical conditions, trophic level, and management conditions. In China, most high-yield reservoirs have a 1-year turnover rate.

Present Status

General Condition

There are now 85,400 reservoirs in China. This includes 300 large reservoirs (>10^7 m^3), 2,100 midsized reservoirs (10^6-10^7 m^3), and 83,000 small resevoirs (Liu 1983; Li and Xu 1987). There is now about 2 x 10^6 ha of reservoirs in China, accounting for 40% of the total suitable culture area in China (Table 1). About 69% of the suitable culture area is used for cultivation.

Yield Level

Yields vary among reservoirs because of variations in latitute, trophic conditions, and management. It can range from 100 to over 1000 kg/ha (Table 2).

Return

The return (harvest) in the Qingshan Reservoir represents the advanced level of reservoir fish culture in China (Table 3). The quality of the return is judged as follows: 30-50%, excellent; 10-30%, good; <10%, poor.

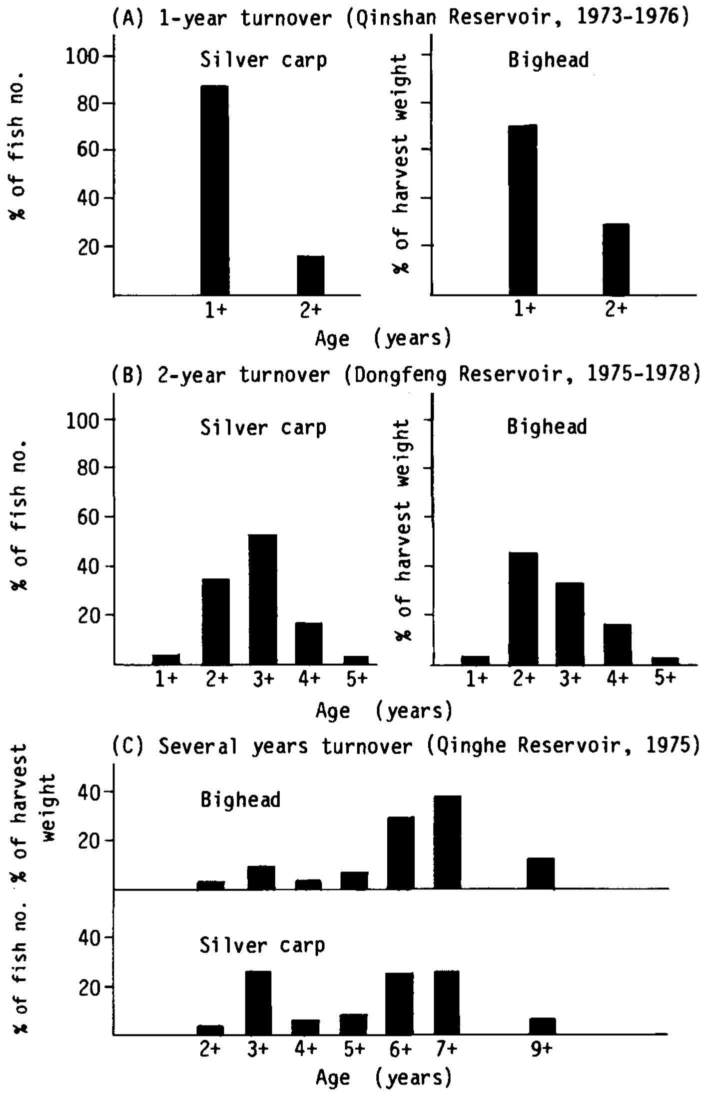

Fig. 3. Types of turnover rates of reservoir fish culture, showing the yield composition of each types.

Table 1. Cultured area and yield of Chinese reservoirs.

	1980	1981	1982	1983	1984	1985
Cultured area (ha)	1266660	1281133	1298753	1298287	1334540	1375667
Total yield (t)	111966	118705	113424	149522	175586	206434
Average yield (kg/ha)	90	90	105	123	135	150

Table 2. Fish productivity in some Chinese reservoirs.

Reservoir	Location	Area (ha)	Yield (kg/ha)	Statistical period
Xianjiang[a]	Eastern China	40000	75	1982-1984
Miyun[a]	Beijing	8000	150	1972-1980
Shahe[a]	Eastern China	1373	225	1981-1984
Qingshan[a]	Eastern China	567	675	1969-1983
Nanshahe[a]	Northwest China	160	525	1968-1975
Xuantan[b]	Centre of China	10.7	1265	1983-1984

[a]No feeding or fertilization.
[b]Feeding and fertilization.

Table 3. Return of bighead and silver carp in the Qingshan Reservoir.

Year	Stocking number ($\times 10^3$)	First return No.($\times 10^3$)	First return %	Second return No.($\times 10^3$)	Second return %	Total return (%)
1972	782	321	41	50	6	47
1973	1524	777	51	55	4	56
1974	1237	474	38	13	10	46
1975	804	310	35	9	11	46
1976	1006	406	40			
Mean			41		8	49

Source: Li (1978)

Table 4. Stocking efficiency in the Qingshan Reservoir.

Year	Stocking[a] No./ha	Stocking[a] kg/ha	Yield (kg/ha)	Stocking efficiency
1972	1380	33.00	825.00	25.0
1973	2685	63.75	740.25	11.6
1974	2190	52.50	496.50	9.5
1975	1425	33.75	605.25	17.9
1976	1770	42.00	565.50	13.5
Mean	1890	45.00	646.50	14.4

Source: Li (1978)
[a]Bighead and silver carp with a total length of 13.2 cm and an average weight of 23.8 g.

Stocking Efficiency

The stocking efficiency of the Qingshan Reservoir also represents the advanced level of Chinese fish culture (Table 4). Stocking efficiency is judged as follows: >10, excellent; 5-10, good; < 5, poor. In general, the stocking efficiency of reservoirs (5-15) is much higher than that os intensive culture ponds (3-6).

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INTEGRATED AQUACULTURE SYSTEMS IN THE SAGULING RESERVOIR, WEST JAVA, INDONESIA

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Abstract *The use of reservoir floating net aquaculture as a planned means of resettlement for 3000 families from the Saguling and Cirata reservoirs in West Java, Indonesia, is described. Over 600 floating net units (7 m by 7 m) were operating commercially by July 1986 in the Saguling Reservoir, producing 1800 t of fish. Research with a 7 m by 7 m unit stocking common carp (Cyprinus carpio) at 71.8 g mean size and 2.4 kg/m^3 produced 1070 ± 151 kg/net in 90 days, with a net profit of IDR 270,000 and a benefit-cost ratio (BCR) of 1.1 (in January 1986, 1 United States dollar (USD) = 1130 Indonesian rupiah (IDR); in September 1986, IDR devalued from 1130 to 1640 per 1 USD). It was noted that the growth rates of common carp slowed toward the end of the culture period; this likely was due to overstocking the unit. A 9 m by 9 m unit was tested at 0.5 kg/m^3 and produced 975.6 kg in 90 days, with a net profit of IDR 655,200 and a BCR of 2.2. Mean food-conversion ratios were 2.3 for the 7 m by 7 m unit and 1.2 for the 9 m by 9 m unit. Large savings in seed and feed costs, the two largest operating costs in floating net aquaculture were realized. Low-cost cages 17-17.5 m^3 in size were developed to stimulate subsistence protein production. Cages stocked with common carp at a mean size of 70.8 g produced 147.3 ± 20.5 kg in 90 days. It is calculated that the protein production of a single cage is sufficient to supply 61% of the protein needs of a family of five persons for 1 year.*

A planned program of aquaculture and fisheries development at the reservoir-engineering phase can assist in meeting the goal of large-scale resettlement, which is an inevitable consequence of impoundment. The potential importance of using reservoirs for expanding food production and employment opportunities is particularly apparent in Asia where the rate of new reservoir development is increasing dramatically (Fernando 1984) and fish is the major source of animal protein (Edwards 1983).

Two new reservoirs in West Java, Indonesia, are the subject of a comprehensive program to develop agriaquaculture and fisheries activities as a planned means of large-scale resettlement for 3000 families from the innundated areas. The resettlement scheme is the direct result of recommendations and research from 1979 to 1986. The reports from the Institute of Ecology (IOE), Padjadjaran University, Bandung, Indonesia (IOE 1979, 1980) detail criteria for a reservoir resettlement program whose primary target group is the displaced peasants and whose aim is to reduce population pressure on the land by making full use of the new water resource through a planned program of agriaquaculture and fisheries development. IOE also developed a plan for an integrated aquaculture and fisheries industry that could provide employment to the displaced population (IOE 1981, 1982).

In 1986, a program was initiated by IOE and the International Centre for Living Aquatic Resources Management (ICLARM) to assist the West Java Fisheries Agency (Dinas Perikanan Propinsi Jawa Barat) in the rapid development of agriaquaculture and fisheries as a resettlement option for displaced families from the Saguling Reservoir and from another downstream Citarum River reservoir (to be filled by February 1988), the Cirata Reservoir (Costa-Pierce and Soemarwoto 1987). This program is funded entirely by the Indonesian State Electric Company (PLN) as part of the loan package from the World Bank for dam construction at Cirata. The IOE/ICLARM program, in cooperation with the West Java Fisheries Agency and directed by PLN, is training 3000 families in low-cost fisheries and aquaculture methods using pilot demonstration projects, conducting research to improve existing systems, and developing a comprehensive management plan in fisheries and agriaquaculture for the Saguling and Cirata reservoirs. In addition, using the previous studies of IOE as a basis, the project is conducting marketing, sociocultural, economic, and environmental studies to support the objective of employing 3000 families in fisheries and aquaculture by 1990.

Reservoir Aquaculture Development in West Java

On the recommendations of IOE, the potential of floating nets as a support system for large-scale resettlement was evaluated at Lido Lake near Bogor in 1982 (Djajadiredja et al. 1982) and at the Jatiluhur Reservoir (Lake Juanda) in 1983. Experiments at Jatiluhur by the Research Institute for Inland Fisheries (RIIF) concluded that a "family unit" consisting of 75-m^2 grow-out and 27-m^2 nursery floating nets could produce an average of 1071 kg of common carp in 4 months. The annual income of such a family unit was estimated at USD 1200 and the internal rate of return was estimated at 36%, for a payback period of approximately 3 years (RIIF 1983). During the experiments at Jatiluhur, 20 residents of the Saguling Reservoir region were trained in aquaculture by RIIF. Some of these first trainees became the pioneers of aquaculture in Saguling when the reservoir was filled in 1985.

Research and training was also conducted by a team of Indonesian scientists from the Lembaga Penelitian (Research Institute) of Padjadjaran University (LPPU) from October 1985 to January 1986. In the research, 1.0-1.3 t/net of common carp was harvested in 3 months, for a net monthly profit of IDR 178,612/net (LPPU 1986) (in January 1986, 1 United States dollar [USD] = 1,130 Indonesian rupiah [IDR]). The LPPU team estimated total capital costs (including labour) for a 7 x 7 x 3 m floating net at IDR 402,200 and operating costs for a

3-month grow-out period at IDR 1,152,000. Furthermore, successful experiments with floating nets were conducted at the Saguling Reservoir after innundation by the West Java Fisheries Agency. These results were directly transferred to prospective and new fish farmers through a new fisheries extension service created by the West Java Fisheries Agency especially for Saguling and Cirata, the Unit Pelaksanaan Teknis (UPT).

Saguling reached its mean high water level in February 1985. By July 1987, over 700 producing aquaculture units were present in the reservoir, consisting of floating net cages, pen systems, and small-scale hatcheries (Fig. 1). Over 300 families are now employed in reservoir aquaculture at Saguling. The number of pen and small hatchery units has remained relatively stable over the past year; however, the number of bamboo cage systems has declined because of the increased popularity of the floating net systems. Although a wide range of systems, unit sizes, and culture practices occur, the most popular system to date is the 7 x 7 m floating net (Fig. 2). In a 1986 survey, 79% of Saguling fish farmers had only one 49-m^2 net that produced a median yield in 75 days of 755 kg (Table 1). The number of floating net systems has been steadily increasing in Saguling, and fish production has now reached an annual capacity of over 1800 t (assuming an annual production of 3 t/net). Fish farmers in Saguling currently culture common carp (Cyprinus carpio) exclusively because it is the most preferred fish of the Sundanese people of West Java.

With the assistance of UPT, fish farmers have formed an association to deal with their common problems of access to credit, problems of marketing, and costs and availabilities of seedstock and feed. With respect to credit availability, two innovative credit schemes now exist. The UPT-initiated scheme has groups of farmers investing 25% of their profits, through the village bank, to assist new fish farmers. The IOE/ICLARM-initiated scheme is derived from the highly successful "Trickle-Up Program" (TUP, 54 Riverside Drive, New York, NY, USA). In addition to these credit programs, Bank Rakyat Indonesia (BRI) provides loans to new fish farmers. BRI initiated its program after the repayment of initial loans made to Saguling fish farmers in 1985 and after a favourable analysis of the profit potential of future aquaculture development in Saguling.

Reservoir Aquaculture Research

The cooperative IOE/ICLARM project has conducted a series of controlled yield trials that first used conventional stocking densities, feeding rates, and fish sizes to replicate the results of the commercial farmers. In one trial using the current commercial model, four replicate 7 x 7 m floating nets were stocked at 2.4 kg/m^3 with common carp averaging 71.8 g. Fish were fed a commercial 24% protein feed (Comfeed, Cirebon, Indonesia) at 3% body weight three times daily. Feeding rates were adjusted biweekly when samplings to determine fish growth rates were accomplished. The floating nets produced 1070 ± 151 kg/net (mean ± SD) after 90 days (Table 2).

Fish growth rates dropped markedly toward the end of the culture periods in all the unites. This was believed to be due to excessive stocking. Therefore, a preliminary yield trial was conducted in one floating net using a lower stocking density. A stocking density of

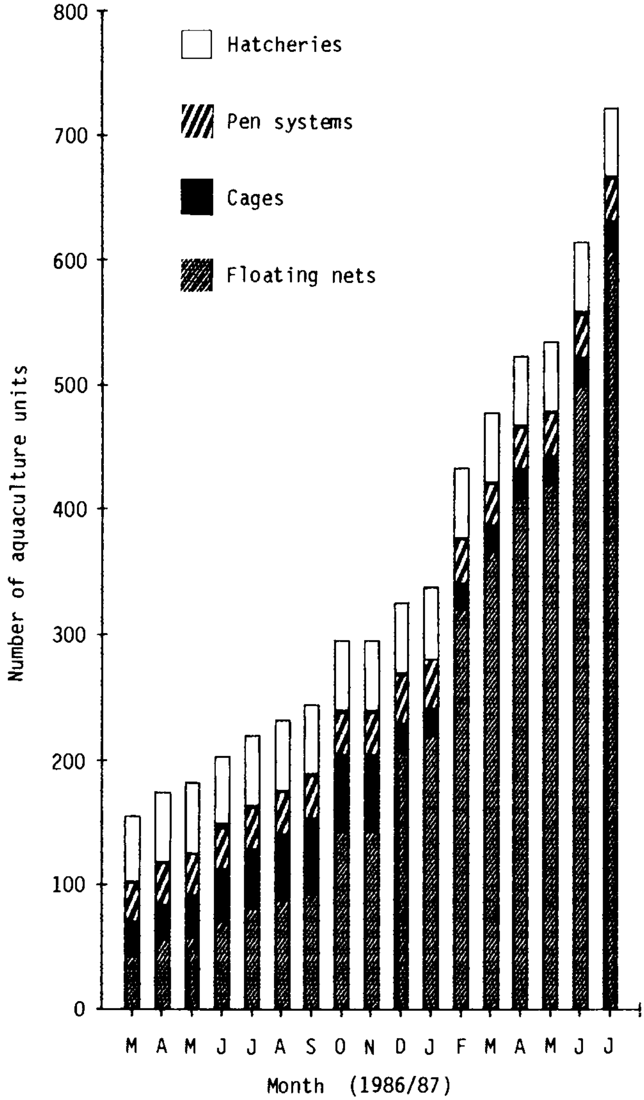

Fig. 1. Aquaculture development in the Saguling Reservoir during 1986/87.

0.5 kg/m^3 of common carp averaging 63 g was used in a 9 x 9 m net; this is 1/3 to 1/16 lower than the density now used by fish farmers in Saguling (see Table 1). After 90 days, the total yield was 976 kg/net (Table 2). This yield is not significantly different (t-test, $p > 0.05$) from the mean yield obtained with 7 x 7 m nets (Table 2). With the 9 x 9 m nets, however, there was a 67% savings in the amount of seed fish and a 50% savings in the amount feed used.

The total cost of the 9 x 9 m net was IDR 486,600 (in September 1986, IDR devalued from 1,130 to 1,640 per 1 USD). For the 7 x 7 m

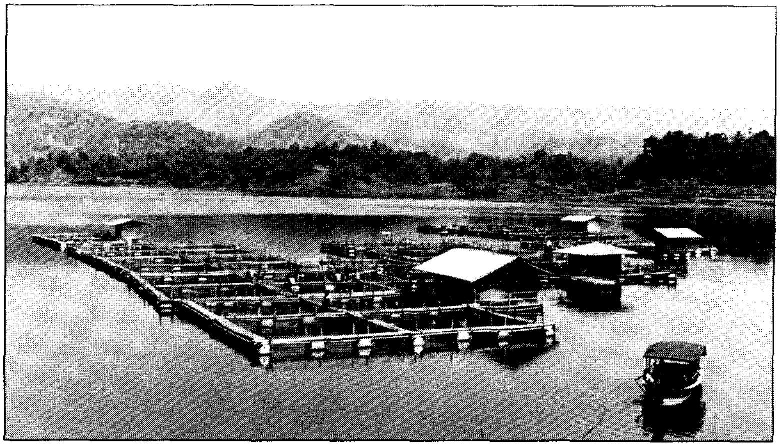

Fig. 2. Floating net aquaculture system used in the Saguling Reservoir, West Java, Indonesia.

Table 1. Biotechnical survey of floating net aquaculture systems in the Saguling Reservoir.

Parameter	Range	Median
Unit size (m^2)	16-2227	49
Stocking rate (kg/m^3)	1.8-8.2	5.8
Culture period (d)	30-150	75
Fish yield (kg/net per culture period)	180-1800	755
Fish growth (kg/net per day)	5-22	11
Total FCR[a]	0.5-2.6	1.5

Source: *Kusnadi (1986).*
[a]Total food-conversion ratio (FCR) equals the total dry weight (kilograms) of commercial fish feed (Comfeed) given during the culture period divided by the total wet weight (kilograms) of fish harvested. Not included in the ratio are the weights of noncommercial feeds such as rice bran, cassava leaf, vegetable leaves, and kitchen wastes (primarily cooked rice) given to the fish during the culture period.

floating net, the total cost was IDR 331,000. A preliminary economic analysis of the large floating net stocked at 0.5 kg/m^3 showed a net profit of IDR 655,200 and a benefit-cost ratio (BCR) of 2.2. For the conventionally sized (7 x 7 m) and stocked (2.4 kg/m^3) over the same 90-day culture period, there was a net profit of IDR 270,000 and a BCR of 1.1. These preliminary results clearly indicate that further research on optimizing the carrying capacity of fish in the floating nets in the Saguling Reservoir is important. Large savings in seed and feed costs, the two largest operating costs in floating net aquaculture, are possible.

Table 2. Results of yield trials using floating nets in the Saguling Reservoir.

Parameter	9 x 9 m net	7 x 7 m nets 1	2	3	4	Mean ± SD
Net size (m^3)	202.5	122.5	122.5	122.5	122.5	
Trial (d)	83	90	90	90	90	
Stocking no.	1576	4170	4425	4122	4006	4181±177
Mean stocking size (g)	63.4	71.9	67.8	72.8	74.9	71.8±3.0
Total stocking weight (kg)	100.0	300.0	300.0	300.0	300.0	300.0
Initial biomass (kg/m^3)	0.5	2.4	2.4	2.4	2.4	2.4
Harvest no.	1540	4162	4316	4062	3978	4129±145
Mortality (%)	2	< 1	2	< 1	< 1	1
Mean harvest size (g)	633.5	217.4	290.6	241.7	293.6	260.8±37.5
Total yield (g)	975.6	905.0	1225.0	982.0	1168.0	1070.01±151.2
Final biomass (kg/m^3)	4.8	7.4	10.0	8.0	9.5	8.7±1.2
Total feed given (kg)	1086.4	1328.2	1806.4	2138.6	1676.3	1737.4±335.1
Net FCR[a]	1.2	2.2	1.9	3.1	1.9	2.3±0.6

[a]FCR, food-conversion ratio.

Subsistence aquaculture systems have also been tested in Saguling by the cooperative IOE/ICLARM project. Floating cages were constructed using a variety of materials (bamboo, wire, net) and stocked with common carp. Cages were located in three villages in the northern part of the Saguling Reservoir where no previous aquaculture activities existed. A trial using seven 17.0-17.5 m^3 floating cages stocked at 2.1-2.5 kg/m^3 with common carp averaging 70.8 g yielded 147.3 ± 20.5 kg/cage after approximately 90 days (Table 3).

Reservoir Fisheries Development

High reservoir aquaculture production through a program of low cost intensification can be realized of it is compared with the potential output of reservoir capture fisheries, e.g., evaluating the capture fisheries potential of the whole of the Saguling Reservoir balanced with its productive potential for aquaculture. In Indonesian reservoirs, annual fish yields range from 22 to 353 kg/ha, with a mean of 177 kg/ha (Baluyut 1983). This average annual yield would likely be the maximum that could be expected from the Saguling Reservoir and translates into a maximum productin of 991 t/year. One 7 x 7 m floating net yields approximately 1000 kg common carp in 90 days (Table 2). With three crops of common carp per year, each net has an annual productive capacity of 3 t. Therefore, the maximum annual fish yield of 991 t could be produced by just 330 7 x 7 m floating nets.

Table 3. Results of yield trials using cages in the Saguling Reservoir.

Parameter	Wire	Net 1	Net 2	Bamboo 1	Bamboo 2	Bamboo 3	Bamboo 4	Mean ± SD
Cage size (m^3)	17.5	17.0	17.5	17.5	17.5	17.5	17.5	
Trial (d)	90	90	90	86	86	86	86	
Stocking no.	608	500	583	537	530	517	547	546±38
Mean stocking size (g)	60.8	82.0	75.0	68.9	69.8	71.6	67.6	70.8±6.6
Total weight stocked (kg)	37.0	41.0	44.0	37.0	37.0	37.0	37.0	38.6±2.8
Initial biomass (kg/m^3)	2.1	2.4	2.5	2.1	2.1	2.1	2.1	2.2±0.2
Harvest no.	586	494	565	527	510	490	522	528±36
Mortality (%)	4	1	3	2	4	5	5	3±1
Mean harvest size (g)	309.7	276.3	300.0	280.8	263.7	259.2	256.7	278.1±20.5
Total yield (kg)	181.5	136.5	169.5	148.0	134.5	127.0	134.0	147.3±20.5
Final biomass (kg/m^3)	10.4	7.8	10.0	8.5	7.7	7.3	7.6	8.5±1.2
Total feed given (kg)	262.5	215.7	250.8	192.4	188.3	190.5	201.0	214.5±30.4
Net FCR[a]	1.8	2.2	2.0	1.7	1.9	2.1	2.0	2.0±0.2

[a]FCR, food-conversion ratio.

There are now well over 600 7 x 7 m nets in the Saguling Reservoir. The IOE/ICLARM project is now assessing the available area and the carrying capacity for floating net aquaculture in the reservoir. Before innundation, it was estimated that 1% of the total area (56 ha) of Saguling would be suitable for year-round floating net aquaculture with no environmental deterioration (RIIF 1983). From water-quality data obtained by the IOE/ICLARM project (unpublished), no measurable environmental deterioration in diurnal oxygen, ammonia, nitrite, or hydrogen sulfide occur if a 7 x 7 m or 9 x 9 m net is used over a reservoir surface area of 400 m^2. Therefore, at least 1400 nets are possible in the 5600 ha Saguling Reservoir. This estimate is very close to that obtained in a recent extensive survey by Lembaga Penelitian, Padjadjaran University (LPPU 1987). With an annual fish production of 3 t/net, the annual aquaculture production of Saguling could reach over 4200 t. At present fish market prices (IDR 1500/kg), this production level would mean a gross annual income from the Saguling Reservoir of USD 3.84 million.

Production from Saguling is already having a major impact on the fish markets and the traditional aquaculture production network of West Java. IOE (1982) predicted a total annual fish demand in the Bandung Regency of 14,400 t, rising to over 16,000 t by 1985. Large fish markets exist throughout heavily populated West Java (IOE 1986) and the ability of these markets to absorb the production from Saguling is unquestioned. In addition, the State Electric Company (PLN) and the West Java Provincial Fisheries Agency are planning to fully develop the aquaculture potentials of the new Cirata Reservoir from 1988 to 1990 and the older Jatiluhur Reservoir. If the number of floating nets in the Cirata Reservoir approaches the number forecast for the Saguling Reservoir, a minimum of 10,000 t of fish could be coming from reservoir aquaculture in West Java by the early 1990's. The Fisheries Agency and UPT are now planning to develop a fish-holding and marketing centre at the edge of the new Cirata Reservoir, which skirts the heavily traveled Bandung-Jakarta highway. This centre will assist reservoir fish farmers to directly market their products and will hopefully prevent drastic fluctuations in fish prices.

Before Saguling, the most popular, rapidly growing aquaculture production systems in the region were the running-water systems (RWS) of common carp. Some 5000 units now exist in West Java (Dinas Perikanan Propinsi, personal communication). However, because of the high capital and operating costs of this system and the advent of the floating net system in Saguling, nearly 50% of these RWS are now unstocked, understocked, or going out of business. A completely new aquaculture production network has been created in West Java (Fig. 3). Before floating nets, RWS absorbed most of the seed fish coming from rice-fish culture systems; pond aquaculture absorbed the remainder. Because the initial capital and operating costs of the floating net system are much lower than those for RWS, the floating net system is able to produce fish more cheaply. RWS fish are now selling wholesale in Bandung at IDR 1800/kg; floating net fish sell for IDR 1400-1500/kg.

The impact of reservoir aquaculture development can also be appreciated from a subsistence viewpoint. Project studies showed that seven cages (17.0-17.5 m^3) produced a mean (±SD) yield of common carp of 174.3 ± 20.5 kg/cage in 86-90 days (Table 3). Because fish are 18%

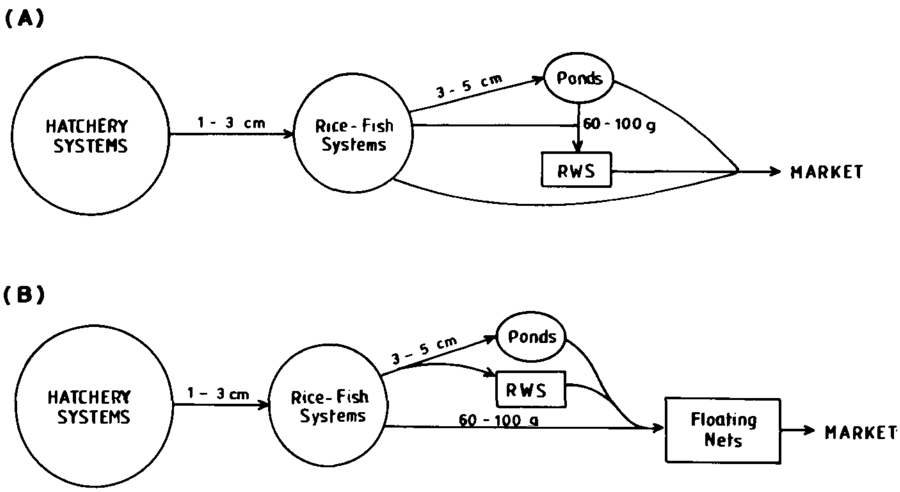

Fig. 3. Changes in freshwater aquaculture production networks in West Java: (A) network before 1985; (B) new, evolving network since 1986. RWS, running-water system.

protein and 70% edible matter (Edwards 1983) and assuming three fish crops per year, one cage produced 79.5 kg protein/year. If we assume a daily protein need of 50 g/person (Edwards 1983) and five persons per family, the total annual protein requirement of a family is 91.2 kg. Therefore, one cage can produce 61% of the total annual protein need for an average five-person family. The development of low-cost, intensive, cage systems could also play a major role in supplying protein to the rural poor displaced by dam construction.

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AQUACULTURE IN RESERVOIRS

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Abstract *Reservoir-based aquaculture is very new and, with certain exceptions, not widely practiced. Nevertheless, it is, in many cases, both technically feasible and desirable, complementing reservoir fisheries by generating additional yields, facilitating food-web manipulation, creating employment, and making use of locally available waste food materials (e.g., rice bran). Two basic methods of reservoir-based aquaculture are distinguished: continuous stocking of fish to support fisheries (practiced in China, Israel, and Sri Lanka) and the use of cages, pens, and enclosures (e.g., China, Indonesia, and the Philippines). Most of this activity is for food production, although caged fish have been used to clean up eutrophic reservoirs. Problems related to drawdown and the multipurpose nature of most reservoirs are discussed. Many problems can be avoided or minimized through careful planning and rigorous implementation, training of farmers, and technical support. It is recognized, however, that aquaculture may not always be desirable, or technically or economically feasible.*

This paper reviews aquaculture in reservoirs, placing particular emphasis on tropical and subtropical areas. It covers culture systems and methods, the purposes of aquaculture, problems peculiar to aquaculture in reservoirs, and possible solutions to these problems. The use of abstracted reservoir water and aquaculture developments downstream of reservoirs (e.g., in spillway canals), however, are not discussed.

There are problems concerning terminology that must be addressed. Reservoirs are typically defined as natural or artifical lakes for the storage of water for industrial and domestic purposes and for regulation of inland waterway levels. Strictly speaking, then, fish ponds could be considered reservoirs. Although the term "reservoir" will be used here in a more restricted sense to describe water-storage bodies that have some additional purpose other than fish culture, there remains some overlap between the use of these terms.

Similarly, there is an overlap between fisheries and aquaculture activities; it can be difficult to distinguish between a fishery supported by a stocking program and extensive aquaculture or ranching. The problem is further compounded by the fact that some countries, such as China, almost invariably refer to stocked water bodies as aquaculture operations. In this paper, the two activities are differentiated by degree; reservoir fisheries that rely on continuous large inputs of fish fingerlings and may be deliberately fertilized are regarded as aquaculture operations.

Overview

In many countries, particularly in Asia, reservoirs form a major component of the lentic freshwater resources. The pace of reservoir construction has accelerated rapidly over the last 40 years. In China, for example, there were only 20 reservoirs in 1949; in 1983, there were 86,000 (Lu 1986). According to Fernando (1980), the area of reservoirs in Southeast Asia can be expected to increase sixfold during the last quarter of this century.

Reservoir-based fisheries are a relatively new phenomenon. In most countries, particularly in Asia, the establishment of productive reservoir fisheries has depended upon stocking and species introductions. The rationale behind these methods and the success of various programs have been extensively evaluated (e.g., Baluyut 1983; Jhingran 1985; Petr 1985).

Aquaculture in reservoirs is also new, having developed only over the last 30 years or so. Reservoirs may be managed either as a complete aquaculture system, similar to fish pond polyculture, or sections may be closed off for aquaculture purposes. Three types of fish- and crustacean-rearing systems may be distinguished: enclosures, in which a natural bay is typically closed off by a solid, net, or mesh barrier; pens, in which the sides are constructed from wood, mesh, or netting, and the bottom is formed by the reservoir bed; and cages, in which all sides and the bottom are enclosed by wood, mesh, or netting (Beveridge 1987). Molluscs are occasionally cultured in reservoirs, usually by the hanging-rope method.

There are many reasons for reservoir-based aquaculture. Fisheries may be entirely or almost entirely dependent upon the regular release of large quantities of fingerlings, either because postimpoundment spawning conditions are poor or because the fish cannot spawn at all. In China, for example, Chinese carp have a comparatively high market value. Moreover, they feed low in the aquatic food web. Because they do not spawn outside their area of origin, however, reservoir fisheries are entirely dependent upon hatchery-reared fingerlings. In many instances, stocked fish make up over 90% of the fish catches (Lu 1986); similar situations exist in other countries.

Cage or enclosure culture of fingerlings, either in support of reservoir fisheries or for sale to pond growers, exists in many countries. In China, there are still acute shortages of fingerlings and reservoirs are increasigly being used to supplement pond-reared supply (Lu 1986). In the Philippines, cage-based hatcheries, which are often divorced from on-growing operations, have proved to be a relatively inexpensive means of rearing tilapia fingerlings, which are then sold to farmers for subsequent pond or cage culture (Beveridge 1984a; Yater and Smith 1985).

Aquaculture is usually established in reservoirs for the production of food fish, either at a subsistence level or as a revenue-generating enterprise. In Singapore during the 1970s and early 1980s, however, bighead carp (Aristichthys nobilis) were being extensively cultured in Seletar and other reservoirs to help control excessive algal growth (Yang 1982).

Culture Methods

In many countries, including China and Israel, reservoirs are managed much like fish ponds: they are stocked with fingerlings and, following a period of growth, mature fish are harvested. A range of extensive (no feeding) and intensive (provision of fertilizers or high- or low-protein feeds) culture methods are employed.

China

China has more than 2×10^6 ha of reservoirs and around 65% (1.4×10^6 ha) of this area is farmed (Li 1986; Lu 1986; Chang 1987). Almost all of the small reservoirs (<670 ha) and many of the large reservoirs are managed as described above and are stocked with common carp (Cyprinus carpio), grass carp (Ctenopharyngodon idellus), silver carp (Hypophthalmichthus molitrix), bighead (Aristichthus nobilis), mud carp (Cirrhinus molitorella), and Wuchang fish (Megalobrama amblycephala) in varying densities and species ratios. Electrical and net barriers are erected to prevent fish escaping into tributaries and net fencing is installed upstream of the turbine inlet pipes. Other measures, such as the manipulation of water levels to facilitate harvesting, the addition of fertilizers and feeds, and the creation of spawning areas, may also be practiced.

Returns are highly variable. In some reservoirs, in some years, nearly 60% of fish stocked may be recovered; in other instances, returns are less than 10% (returns of 50% are regarded as excellent; 10-30% as good; < 10% as poor) (Li 1986). Areal yields from reservoirs, which, for China, averaged 113 kg/ha in 1983 (Li 1986), are only around two-thirds of those reported from lakes managed in the same way (Zhu 1980; FAO 1983). As might be expected, yields are highly variable, both between reservoirs (<50 to >1500 kg/ha) and between years, as a result of not only geographic location, weather, and differences in productivity but also because of differences in stocking rate (Fig. 1), reservoir size (Fig. 2), management (feeding, fertilization, and fishing pressure), and the presence of predatory fish (Li 1986).

Israel

In Israel, a number of the many water-storage reservoirs (10-40 ha in area, 5-7 m deep) that were originally constructed for cotton irrigation are now also being successfully used to culture fish (Sarig 1984; Hepher 1985). These reservoirs are deep compared with typical fish ponds (1-2 m), causing problems for seining but permitting greatly increased areal stocking rates because of the improved oxygen conditions and increased dilution of fish waste metabolites. To facilitate seining, terraces may be constructed; this ensures that the depth at seining does not exceed 1 m. An electrically powered lift net, 12 m x 12 m, may also be installed to facilitate routine sampling (Fig. 3).

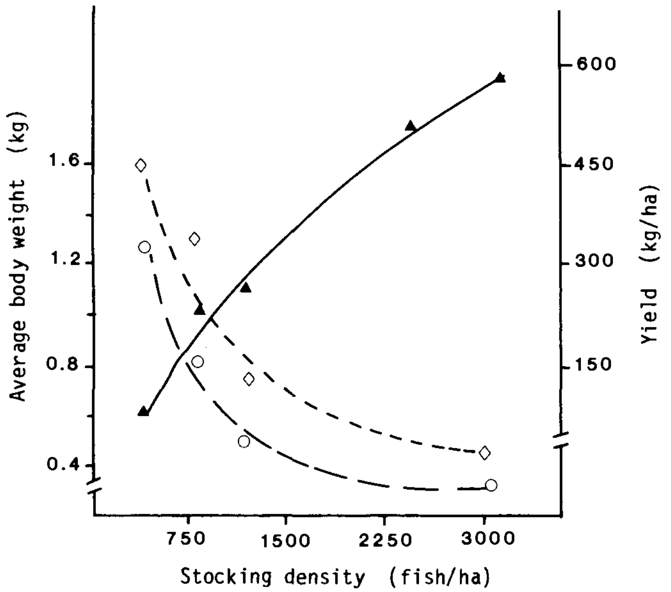

Fig. 1. Relationship between stocking density, mean body weight at harvest (○, silver carp; ◇, bighead) and areal yield (▲) of fish after one growing season in the Nanshahe Reservoir, China (Li 1986).

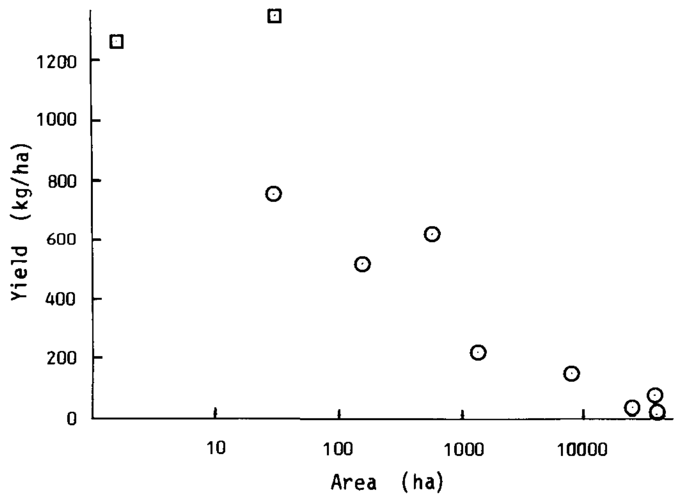

Fig. 2. Areal yield versus reservoir size in China. Open squares represent systems where artificial feed or manure is added (Li 1986; Lu 1986).

A range of species may be stocked in polyculture, including tilapia, mullet, and carp. Stocking ratios vary considerably; typically, they are as follows (fish/ha): common carp, 10,000; tilapia (*Oreochromis niloticus* x *O. aureus*), 5,000; mullet (*Mugil cephalus*),

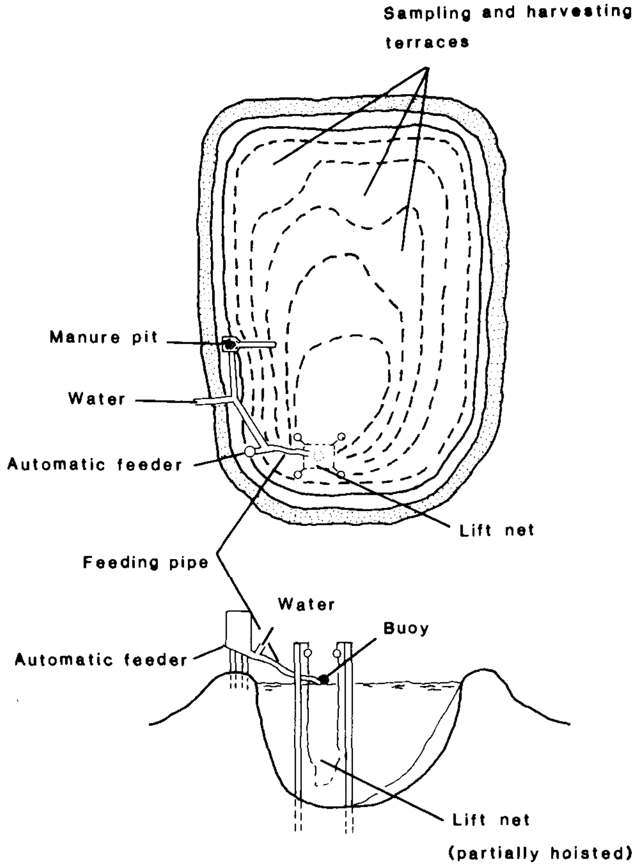

Fig. 3. Sketch of a crop irrigation - aquaculture reservoir in Israel (Hepher 1985).

2,000; silver carp, 300. Annual yields in excess of 10 t/ha have been reported and, as the reservoirs are intensively manured, feed-conversion ratios are excellent.

Sri Lanka

Sri Lanka has around 50,000 seasonal tanks (reservoirs) covering more than 100,000 ha that were built for irrigation and domestic purposes (Fernando and De Silva 1984). These tanks are generally small (<80 ha) and store water for 6-10 months of the year. Since 1979, the Ministry of Fisheries has pursued a program of developing as many of these tanks as possible for fish culture. By 1985, more than 200 were being regularly stocked with exotic Indian major carp, Chinese carps, tilapia, and the indigenous Labeo dussumieri. In addition, many of these reservoirs are fertilized with manure or effluent from biogas plants. Data for 1984/85 show that 1137 ha of seasonal tanks were stocked and that 422 t, or 1.3% of the country's total freshwater fish supply, was being produced from these reservoirs

(Ministry of Fisheries, Sri Lanka). This is equivalent to an areal yield of 372 kg/ha, although yields are considerably higher in some parts of the country (Table 1).

Innovative Methods

Enclosures and pens are not yet widely used in reservoirs. In recent years, however, China has experimented with a number of innovative, reservoir-based, enclosure methods (Lu 1986). In Chang Shouhu Reservoir, Sichuan Province, drawdown has been used to produce large numbers of fingerlings. Before refilling, a 260-ha embayment was fenced off with 2.4-cm mesh netting. A second, smaller mesh net barrier was then constructed in the inner part of the bay and 5.8×10^6 grass carp, silver carp, and bighead carp fry (1.6-2.6 cm) were stocked in this inner area during early June. When the fry attained a length of about 6 cm, they were released into the outer area. By the end of October, 3.5×10^6 fingerlings of 13-19 cm had been produced and were ready for either release into the main body of the reservoir or for sale to other on-growing enterprises.

A detailed economic and technical analysis of an alternative enclosure method has been carried out at Sha Hezi Reservoir, Jilin Province, China (Lu 1986). The upper reaches of the coves within this impoundment area have been converted into 13 terraced enclosures, totaling 31.6 ha, by constructing earth walls. Construction costs were similar to those for earth ponds. Around 4.2×10^6 carp fingerlings are produced each year at a net profit of USD 65,700.

The use of cages in reservoirs is widespread (see Coche 1983). Cage designs have recently been reviewed by Beveridge (1987). In Europe and North America, intensive cage culture, usually of salmonids or other carnivorous, high-value species, predominates; however, for technical, planning-related, and environmental reasons, cage culture is only practiced to a limited extent in reservoirs (Hays 1980; Jarrams et al. 1980; Beveridge 1984b, 1987). In tropical and subtropical areas where fish that feed low in the food web (e.g., tilapia and carp) are extensively and semi-intensively cultured, there

Table 1. Seasonal tank fish production in the Hambantoba and Moneragala districts of Sri Lanka.

District	Year	Tanks	Area (ha)	Production (kg)	Areal production (kg/ha)
Hambantoba	1983/84	15	39.5	17578	443
	1984/85	4	11.0	7936	721
	1985/86	18	43.5	21115	485
Moneragala	1983/84	27	134	71150	531
	1984/85	25	139	110000	791
	1985/86	32	148	125000	845

Source: Udawalawe and Muruthawela Fisheries Research and Breeding stations, Sri Lanka.

is increasing interest in cage culture in reservoirs. At present, however, production on any scale is limited to only a few countries (e.g., China, Indonesia, and Côte d'Ivoire).

Problems of Reservoir-Based Aquaculture

Reservoirs have certain characteristics that make them less than ideal for aquaculture. In addition, reservoirs are multipurpose, and this can lead to a conflict of interests between fish farmers and other users.

Drawdown influences many aspects of the physicochemical environment of reservoirs, with a corresponding effect on productivity and fish production (Bernacsek 1984). Drawdown can also adversely affect spawning, necessitating a fingerling-stocking program, and may cause upwelling of deoxygenated, H_2S-rich, hypolimnetic water. If the drawdown is greater than 4 or 5 cm, fish culture in pens and fixed cages becomes impossible because of prohibitive cost of establishing sufficiently long support posts (Beveridge 1987). The mooring of floating cages also becomes increasingly difficult and costly as drawdown increases and, in some situations, may preclude the establishment of all but the most profitable, commercial operations.

In small, stocked reservoirs, drawdown may not always be a problem. In fact, drawdown often facilitates harvesting, although it may limit the length of the grow-out period, as in Israeli and Sri Lankan seasonal reservoirs. As mentioned earlier, drawdown can also be advantageous in the establishment of the type of enclosure fry-production system that has recently been developed in China.

The effects of submerged trees and other terrestrial vegetation on fish yields in reservoirs is still a matter of considerable debate (Bernacsek 1984; Kapetsky and Petr 1984; Ploskey 1985). Unless the reservoir basin is surveyed and areas for enclosure, pen, or fixed cage culture are identified and cleared at the preimpoundment stage, however, it may be impossible to rationally plan and establish this type of aquaculture. Floating cage culture is unlikely to be hampered to the same degree. Other problems experienced in enclosure, pen, and cage culture operations in reservoirs include predation, poaching, and floating vegetation.

The establishment of enclosure, pen, or cage culture in a reservoir can alter or limit its value as a multipurpose resource (for reviews, Beveridge 1984b, 1987; Phillips et al. 1985). Enclosures and pens, in particular, take up previously unoccupied space, alter current and flow regimes, and, hence, sedimentation patterns, and degrade the scenic value of a site. Their physical presence alone may disrupt spawning and interfere with navigation or restrict access from shore-based villages to open waters, as has occurred in Laguna de Bay in the Philippines (Beveridge 1984b).

Intensive fish culture inevitably results in the introduction of wastes (uneaten food, excreta, and egesta) that stimulate productivity but can also, if excessive, adversely affect water quality. A deterioration in water quality can stress or increase mortality among wild and farmed fish stocks and may reduce potability or affect the value of water for irrigation or recreational use (e.g., swimming, bathing). At the opposite extreme, extensive cage culture can result in the overcropping of plankton and, hence, a depressed growth of the caged stock and increasing reliance on supplementary feeds. Another possible impact of aquaculture ventures in reservoirs is the accidental introduction of exotic species or disease organisms.

Although much has still to be learned about reservoir-based aquaculture, most of the problems outlined in this paper are readily avoidable and any adverse effects can be greatly minimized. Careful planning and proper implementation can ensure that cage, pen, and enclosure culture developments do not interfere with navigation or access. Examples from the Philippines underline the necessity for careful and sensitive planning of pens and, enclosures, in particular, which, by virtue of their size and capital cost, can result in the privatization of large expanses of a common resource by the more affluent sectors of society with consequent social disruption. Risks of introducing exotic species or disease organisms can be minimized by choosing the appropriate species and source of fingerlings. Simple, preliminary, yet effective models have been developed for estimating the carrying capacity of sites for different types of culture (see Beveridge 1984b, 1987; Phillips et al. 1985).

Discussion and Conclusions

Fish production from reservoirs should be accorded a high priority in many parts of the world in view of the importance of fish as a staple food (Petr 1983) and a revenue-generating source. In China, over 90% of reservoirs in some provinces are now financially self-sufficient, with aquaculture-based fisheries for 34.5% of the total revenue (Lu 1986).

Aquaculture in reservoirs is, in many cases, both technically feasible and desirable because it can create employment, generate additional food and income, and support or complement fisheries and other activities while utilizing previously unexploited resources such as waste agricultural and industrial produce (Sarig 1984; Little and Muir 1987). Careful planning that recognizes local socioeconomic conditions and the control of developments is essential, as are training and proper support. In some reservoirs, however, there may be insurmountable technical difficulties associated with cage, pen, or enclosure culture. Where potable water is abstracted, it may be desirable to greatly restrict or even discourage intensive aquaculture activities. Preimpoundment, soil and vegetation surveys, with minor earth moving or vegetation removal, would help in the rational development of aquaculture and the maximization of yields.

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DISCUSSION

Cage culture is becoming increasingly important in Asian reservoirs. The case study of Indonesia, where the displaced people from the impoundment area have been made to undertake cage fish culture, was considered as a good example of involvement of fisheries activities in reservoir planning.

Problems involved in cage culture practices in Asian reservoirs were highlighted and ranged from site and species selection to poaching and damage to nets by aquatic mammals. The importance of two-stage culture was discussed and it was recognized that such a system could be used to provide a harvest income to the farmer throughout the year without additional capital inputs. The merits and demerits of pond supplementation was highlighted. The existing culture systems use a wide variety of practices ranging from no artificial supplementation to intensive feeding. The need for further research to quantify the degree of supplementation required in different water bodies was recognized.

The concept of stocking efficiency to evaluate stock and recapture success in Chinese reservoirs was discussed. This useful index is applicable in other countries where reservoirs are stocked. It was also pointed out that in reservoirs in which cage- or pen-culture operations are carried out with feed supplementation that a significant "indigenous foraging fauna" tends to develop around the cages or pens. The possibilities of using this resource, either for direct human consumption or as a basis for the diet of cultured fish, was dealt with in detail. Such a practice would enable a fish farmer to decrease feed costs or increase income directly by selling the by-product. The possibilities of integrating cage culture with duck or chicken farming were evaluated briefly. It was felt there is a need for research in this area to evaluate the positive effects of such a practice.

The need for technology transfer between countries was discussed. It was agreed that there is a large volume of literature available in national languages that is not readily available to other countries in the region. The need to translate this material was emphazised.

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