Reservoir Fisheries of ASIA

Proceedings of the 2nd Asian reservoir fisheries workshop held in Hangzhou, People's Republic of China, 15–19 October 1990

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Abstract / Résumé /Resumen

Abstract — This publication presents the results of the second workshop on reservoir fisheries in Asia, which was held at Hangzhou in the People's Republic of China on 15–19 October 1990. The major areas of reservoir fisheries research discussed were limnology, changes that follow impoundment, fisheries management and modeling, and culture techniques. A total of 25 presentations encompassing various aspects of reservoir fisheries are included in this volume: of these, nine dealt with practices in the People's Republic of China, most of which are only now becoming known to researchers outside that country. In addition to the papers on various aspects of reservoir fisheries management presented by researchers from the 11 participating countries, summaries of the discussion sessions, which were a major element of the workshop, and a set of recommendations made by the workshop participants are presented here. The general recommendations encompass the research needs for development of reservoir fisheries in Asia but are also relevant to developing countries elsewhere.

Résumé — Cette publication a trait au deuxième atelier sur les pêches en réservoir en Asie, qui a eu lieu à Hangzhou, en République populaire de Chine, du 15 au 19 octobre 1990. Parmi les principaux thèmes de recherche qui y ont été abordés, mentionnons la limnologie, les changements qui résultent de l'endiguement des eaux, la gestion et la modélisation dans le domaine des pêches et les méthodes de culture. On trouvera dans ce volume 25 exposés portant sur divers aspects des pêches en réservoir; neuf d'entre eux ont trait aux pratiques utilisées en République populaire de Chine, dont la plupart n'étaient pas connues jusqu'à maintenant des chercheurs de l'extérieur de ce pays. Outre le texte des communications présentées par les chercheurs des 11 pays participants, ce volume comprend des résumés des séances de discussion, qui ont été un élément primordial de l'atelier, ainsi qu'une série de recommandations faites par les participants. Les recommandations d'ordre général portent notamment sur les besoins en matière de recherche pour le développement des pêches en réservoir en Asie et elles peuvent également s'avérer pertinentes pour d'autres pays en développement.

Resumen — Esta publicación presenta los resultados del segundo taller sobre pesquerías de acuacultura, celebrado en Hangzhou, en la República Popular China, del 15 al 19 de octubre de 1990. Los principales temas examinados relacionados con las pesquerías de acuacultura fueron limnología, cambios subsiguientes al rebalse, gestión y administración de pesquerías y establecimiento de modelos, y técnicas de reproducción. En este volumen se incluyen un total de 25 presentaciones que abarcan diversos aspectos de las pesquerías de acuacultura: de éstas, nueve tratan de las prácticas seguidas en la República Popular China, la mayor parte de las cuales sólo ahora se están dando a conocer a investigadores ajenos a ese país. Además de las diversas ponencias sobre aspectos diversos de la administración y gestión de las pesquerías de acuacultura, presentadas por los 11 países participantes, también se incluyen resúmenes de las sesiones de deliberación, que constituyeron un elemento principal del taller, y un conjunto de recomendaciones formuladas por los participantes en dicho taller. Las recomendaciones generales abarcan las necesidades de investigación para el desarrollo de pesquerías de acuacultura en Asia, si bien son asimismo pertinentes en cualquier otro país en desarrollo.

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Foreword

The Fisheries Program of the Agriculture, Food and Nutrition Sciences Division of the International Development Research Centre (IDRC) continues to have a major interest in the improved management and use of reservoirs. We are pleased to have funded this workshop held in Hangzhou, People's Republic of China, 15–19 October 1990 and the publication of the proceedings. This is the second Asian reservoir meeting funded by IDRC; the proceedings of the earlier one was published as *Reservoir Fishery Management and Development in Asia: Proceedings of a Workshop held in Kathmandu, Nepal, 23–28 November 1987* (IDRC, Ottawa, ON, Canada, IDRC-264e, 1988).

Both meetings are part of our program to encourage more discussion and exchange of information among scientists working in this sector. As indicated in this and the earlier proceedings, IDRC feels that reservoirs are an important and expanding resource that requires careful management. Also, as noted by Professor De Silva in his introduction, we are seeking to document more and more of this information to encourage comparison of the different management strategies based on available scientific information. Where questions remain, IDRC — with other donors and national governments — seeks to fund projects to answer them and to provide information for the development of policy and other management options.

We hope that interested scientists and policymakers in this sector will note the recommendations section. Some may find this reminiscent of other meetings; if this is so, it confirms concerns indicated by some workers about the difficulty of changing the present approaches. This is an item that should be of concern to reservoir workers in Asia and we would welcome comments on means of changing this situation. We feel that some regional progress has been made since the last meeting in Nepal. We draw readers attention to the consideration of the Chinese experience in terms of a more integrated approach to reservoir development, the need for networking, and the possibility of a training course being held with the next workshop.

We thank the staff of the Ministry of Water Resources for hosting this workshop and for the fine local arrangements provided. China was chosen as the site of this workshop because participants at the fist workshop pointed out that China had a vast amount of experience that was not widely known. A sampling of this information is documented here. Participants were also able to visit a number of Chinese reservoirs during their stay and this was acclaimed by all to be one of the highlights of the workshop. Finally, IDRC would like to thank Professor De Silva for organizing and chairing the workshop, and editing these proceedings. He was the key figure in this effort.

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Introduction

This volume contains the papers presented at the second Asian Reservoir Fisheries Workshop, held in Hangzhou, People's Republic of China, 15–19 October 1990. The workshop brought together 32 reservoir fishery scientists from 11 countries. Fisheries are an increasingly important secondary user of reservoirs in Asia. Reservoir fisheries provide a source of relatively cheap animal protein to the poorer sectors in the community, as well as employment opportunities. As the number of reservoirs continues to grow, governments in Asia are beginning to pay increasing attention to the development of fisheries in these reservoirs.

Until recently, there had been little research on reservoir fisheries in most of Asia, and what had been carried out was in isolation and primarily determined by the interests of individual researchers. Technologies developed and adopted in some countries, such as integrated management of small-sized reservoirs in China, remain almost unknown elsewhere.

A primary objective of workshops of this nature is to create an awareness of such practices and management measures among scientists in the region, and to develop a scientific approach to sustainable management.

The proceedings are divided into four sections: limnological aspects; evaluation of postimpoundment changes and existing fisheries in selected reservoirs; reservoir fishery management practices and modeling; and culture techniques. Some presentations could easily fall into more than one section. The divisions were made more for convenience and clarity than for strict scientific accuracy.

Reservoir fisheries are essentially artisanal and management, therefore, must be based on a multidisciplinary approach in which the socioeconomic aspects of the reservoir community play an important role. It is becoming increasingly clear that integrated management of the "system" is more desirable, and that fisheries scientists must work in conjunction with managers and planners of catchment and downstream areas.

It is hoped that this volume will add to our knowledge of reservoir fishery practices in Asia, and contribute to better and more coherent management of this vast resource and to optimal production of fish through scientific management.

Sena S. De Silva

Recommendations

Classification and Modeling

(1) A classification system for reservoirs based on morphometric, physical, and biological parameters must be developed to make findings from reservoir fisheries management and from development research in different countries more comparable. However, the workshop recognized that, at present, insufficient information is available to develop such a classification. As a first step, the classifications used for fisheries management and development in each of the participant countries should be documented.

(2) The workshop recognized that attempts to use the morphoedaphic index (MEI) as a predictive parameter for fish yield for Asian reservoirs have not been successful for a number of reasons. The foremost is that Asian reservoirs do not conform to the requirements on which the original MEI concept is based. The workshop reiterated the need to develop models for reservoir fisheries management and development along three lines:

- Predictive models for fish yield from capture- and culture-based reservoir fisheries;
- Easily measurable, and hitherto unexplored, parameters for predictive purposes and for management; and
- Trophic dynamic models to improve understanding of reservoir ecosystems and their dynamics.

The delegates further appreciated that, since the last workshop, there had been research directed toward developing predictive and fisheries management models in Asia, and that further refinement and validation of these models should be encouraged.

Data Management, Presentation, Analyses, and Dissemination

Participants recognized that a number of shortcomings exist in the collection, storage, management, and analysis of data pertaining to reservoir fisheries research. It was also thought that scientists often collect too much, and irrelevant, data at a great cost and effort, especially in respect of limnological data.

There is a need to differentiate between data collection for detailed limnological studies and data collection with respect to factors contributing to sustainable yields for capture fisheries, yield predictive modeling, culture-based fisheries, and integrated reservoir fisheries management.

(1) The workshop recommended that attempts should be made to provide suitable training, nationally or regionally, in the management and analysis of data. Use of computers and software packages that are readily available or are used by other groups of researchers, should be encouraged.

(2) It was agreed that all scientific contributions should have complete descriptive statistics and that all nations that have reservoir fisheries should endeavour to have some personnel trained in multivariate statistics and modeling methods.

Systems Approach

The workshop recognized that value of the systems approach adopted in China, particularly with respect to integrated culture in small reservoirs. It was suggested that this approach might be useful for other countries to adopt after suitable modifications, particularly with respect to the social conditions in each country.

Environmental Impact Assessment and Conservation

Participants recognized that, in most countries in Asia, proper environmental impact assessment (EIA) is done, especially with respect to dams that create large reservoirs. However, in most instances, continuous EIA is not carried out.

(1) The workshop recommended that EIA should be an integral component of the day-to-day management of a reservoir.

(2) The workshop also recognized that there is an increased need to incorporate certain managerial practices adopted for fisheries development into routine EIAs.

(3) The workshop also recommended that special attention be paid to the conservation of the natural flora and fauna in reservoirs and interconnected waterways.

Management, Regulations, and Policies

(1) The role of stocking practices in yield enhancement and management, particularly in large reservoirs in Asia, is not fully understood. The workshop recognized the need for further research on the role of stocking in the management of large- and medium-sized reservoirs. It also recognized that such studies might account for the importance of introduced species and their influence on both fish production from indigenous species in the reservoir and indigenous flora and fauna. The workshop recommended that attempts should be made to develop models to determine the optimal stocking practices in reservoirs.

(2) The participants agreed that efforts are needed to develop a suitable data base to help evolve appropriate predictive models for estimating the potential yield from reservoir ecosystems. Likewise, suitable stock-assessment models must be developed for multispecies and multimeshed gill-net fisheries of Asian reservoirs.

(3) The lack of regulation and the difficulties encountered in the enforcement of such measures for conservation and optimum utilization of fishery resources in most Asian reservoirs were discussed. The workshop felt that, as reservoir fisheries become increasingly important in Asia, the need to develop regulatory measures and evolve enforcement measures will increase. The participants believed that the development and enforcement of regulatory measures should be done in conjunction with those who fish, taking socioeconomic aspects into consideration. It was thought that documentation of the existing regulatory measures in different countries would be useful.

(4) The participants recommended that, to derive the desired socioeconomic benefits from reservoir fisheries, the people displaced by the creation of new reservoirs should be resettled along the periphery of reservoirs and trained in fishing or other fishery activities that will be developed in the reservoirs. Efforts should be made to organize cooperative societies to manage fishing and marketing of fish caught from the reservoir.

Socioeconomic Aspects

(1) The reservoir fisheries in Asia are, by and large, small-scale artisanal fisheries. The participants recognized that there is a dearth of research on socioeconomic aspects of reservoir fisheries in Asia. The workshop recommended that research on socioeconomics be recognized as a priority area and that every effort should be made to encourage such research.

(2) A detailed study was recommended to determine the socioeconomic inputs into the integrated management of the small-sized reservoirs in China, and to evaluate their applicability and relevance to other Asian countries.

Fishery Design

It was noted that, in most Asian countries perhaps with the exception of the People's Republic of China, fisheries are not considered in the planning of reservoir construction. However, fisheries are becoming an increasingly important secondary user of reservoirs, and they provide a cheap source of protein and employment opportunities to poor sectors of the community living in the vicinity of a reservoir. Therefore, it was recommended that reservoir fisheries scientists become involved in reservoir planning and provide inputs to engineers and planners with respect to timber clearance, facilities to prevent fish escape, provision of hatcheries and rearing ponds, and the intended fishing operations.

Fish Biology

Gaps in our knowledge of the basic biology of species, both stocked and naturally recruited, have hindered optimal utilization of reservoirs as a protein source. The workshop recommended that studies on the biology of stocked and indigenous species, particularly with respect to their spawning habits and age structure, should be undertaken. International cooperation among researchers needs to be encouraged.

(1) Cage culture is becoming an increasingly important component of most reservoir fisheries in Asia. The workshop recommended an increase in cage-culture research, particularly on husbandry and diseases; the search for new, suitable species for intensive culture; development of low-cost feeds; and determination of optimal ratio of cage area to open water area.

Asian Reservoir Fisheries Network

The importance of a network of reservoir fishery scientists in Asia was recognized by the participants. Existing groups, such as the Network of Tropical Aquaculture Scientists (NTAS), the Network of Tropical Fisheries Scientists (NTPS), the Asian Fish Nutrition Network, and the Network of Fish Diseases, cannot be used for this purpose because these networks have their own objectives. In view of the diversity of reservoir fisheries in Asia and the multidisciplinary approach needed for reservoir fishery management, the establishment of a network of reservoir fishery scientists in Asia is most desirable for effective research, coordination of research effort and activities, and dissemination of research findings on reservoir fisheries. The possibility of attaching this proposed network to the Asian Fisheries Society should be explored.

Information Transfer

The workshop recognized the need to disseminate information more widely and recommended that a mechanism be evolved to translate key information and publications available in national languages, particularly Chinese, into English, and to develop audiovisual material on existing, successful reservoir fishery practices in different countries.

It was also suggested that, in the long run, reservoir fishery scientists should strive to inaugurate a journal to disseminate research findings.

Third Asian Reservoir Fishery Workshop

All participants felt that the workshop had helped them interact with reservoir fishery scientists from other countries, discuss their research findings, and observe the practices in another country. The workshop also enabled them to recognize the focus on research priorities for the future.

The participants were satisfied with the manner in which the workshop was conducted, and urged that the practice of having a field trip between the technical sessions be continued.

The participants strongly recommended that a third Asian reservoir fishery workshop be conducted in 2–3 years, and that, if funds were available, the workshop be held back-to-back with a short training course on some aspect of reservoir fisheries management and development.

Section 1 — Limnology

Limnology and Primary Production of Kaptai Lake, Bangladesh

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Seasonal variations in different physicochemical and climatic factors of Kaptai Lake, and the degree of correlation among these factors are presented. The lake water was slightly alkaline and hard. In the monsoon months (June–September), water transparency was low due to high turbidity. Physicochemical values were normally high in the winter and postwinter months. Both direct and inverse correlations were found among the various parameters. A higher productivity was observed during the premonsoon period, when the reservoir had the lowest water level. Gross energy production ranged from 1 848 to 8 186 MJ/m^2 per year; average gross carbon production was 135 g/m^2 per year. Primary productivity was inversely correlated ($r = -0.88$, $p<0.001$) to water level.

Kaptai Lake was impounded by damming the Karnaphuli River at Kaptai in the Rangamati Hill Tracts District of Bangladesh in 1961. It has a surface area of 68 000 ha making it one of the largest reservoirs in Southeast Asia. The lake was created primarily for hydroelectric power generation; however, it has also made a substantial contribution to the national economy through freshwater fish production, navigation, irrigation, and flood control.

Information on physicochemical factors and energy transformation in the lake is scanty. The first investigation of limnological parameters of the lake was done by Sandercock (1966); the limnology and phytoplankton of the lake were studied by Chowdhury (1980), Chowdhury and Mazumder (1981), and Chowdhury and Khair (1982, 1983); and the hydrobiology of the lake was studied for 1 year by the Aquatic Research Group (ARG 1986). Jenkins (1985) suggested a long-term research program to formulate a sound fisheries management procedure. Rahman (1988) reported the morphometric details of the reservoir. Our work was undertaken to evaluate the potential productivity of the lake and to provide information for fisheries development and management planning.

Materials and Methods

The study was conducted from April 1988 to March 1989. Water samples for physicochemical parameters were collected from five sampling stations (Rangamati, Balukhali, Subalong, Kaptai, and Naniarchar). Water level and rainfall data were obtained from the hydroelectric power project at Kaptai. Air and water data were obtained from the hydroelectric power project at Kaptai. Air and water temperatures were recorded using a glass thermometer and water transparency was measured by Secchi disk. Other parameters, such as pH, dissolved oxygen, free carbon dioxide, total hardness, alkalinity, chloride, nitrite, ammonium nitrogen, ammonium ion, and ammonia were estimated with a HACH test kit (Model FF-1A).

Primary productivity was estimated by the light-and-dark-bottle technique (Benton and Werner 1965) incubated for 24 h. The results obtained from the Winkler titration were extrapolated using an oxycalorific coefficient of 3.51 (Winberg 1960) to calculate energy production (in MJ/m^2 per day). The plankton biomass, organic matter, and carbon production were calculated on the basis of gross O_2 production (g O_2) using the following formulae: carbon = g $O_2 \times 0.375$ (g); organic matter = g $O_2 \times 0.690$ (g); and plankton biomass = g $O_2 \times 3.300$ (g).

Results and Discussion

The mean monthly values of the various physicochemical parameters are shown in Fig. 1.

The water level of the lake varied; it increased from July to October and was largely dependent on rainfall and the extent of hydroelectric power generation at Kaptai. The highest water level of 108.4 m above mean sea level (MSL) was recorded in October after the monsoons; whereas the lowest level of 82.7 m above MSL was recorded during the dry period in May and June.

Air temperature was higher than the water temperature throughout the year. Highest air and water temperatures of 32.5°C and 31.0°C and lowest of 23.2°C and 21.0°C were recorded in July and January, respectively. Water temperature at the Naniarchar sampling station was slightly lower than at the other four stations throughout the year. Unstable seasonal thermoclines and thermal stratification occur in summer (March–May) and in the postmonsoon months (September–October). The limit of visibility at all the stations during the winter months (November–February) was high; whereas low visibility prevailed in the monsoon months.

No marked variations in dissolved oxygen content among different stations were observed. The fluctuation of average dissolved oxygen content was a minimum of 5.75 mg/L in September and a maximum of 7.0 mg/L in February. Free carbon dioxide content, showed a wide variation in different months; maximum concentration (12.9 mg/L) was observed in September and the minimum (4.5 mg/L) was observed in March and June.

Total hardness ranged from 17.3 to 54.7 mg/L. Variation among the different stations was small, except for a sudden fall in August. Monthly variations in alkalinity were small among the different stations. The highest value (53.0 mg/L) was recorded in March and April, the lowest value (33.5 mg/L) in August.

The mean pH values were in the alkaline range and varied between 7.0 and 7.8. Almost neutral pH was recorded at all stations in August.

The mean monthly chloride concentration varied between 11.25 and 17.50 mg/L. The minimum was recorded during the monsoon months and the maximum during December to April.

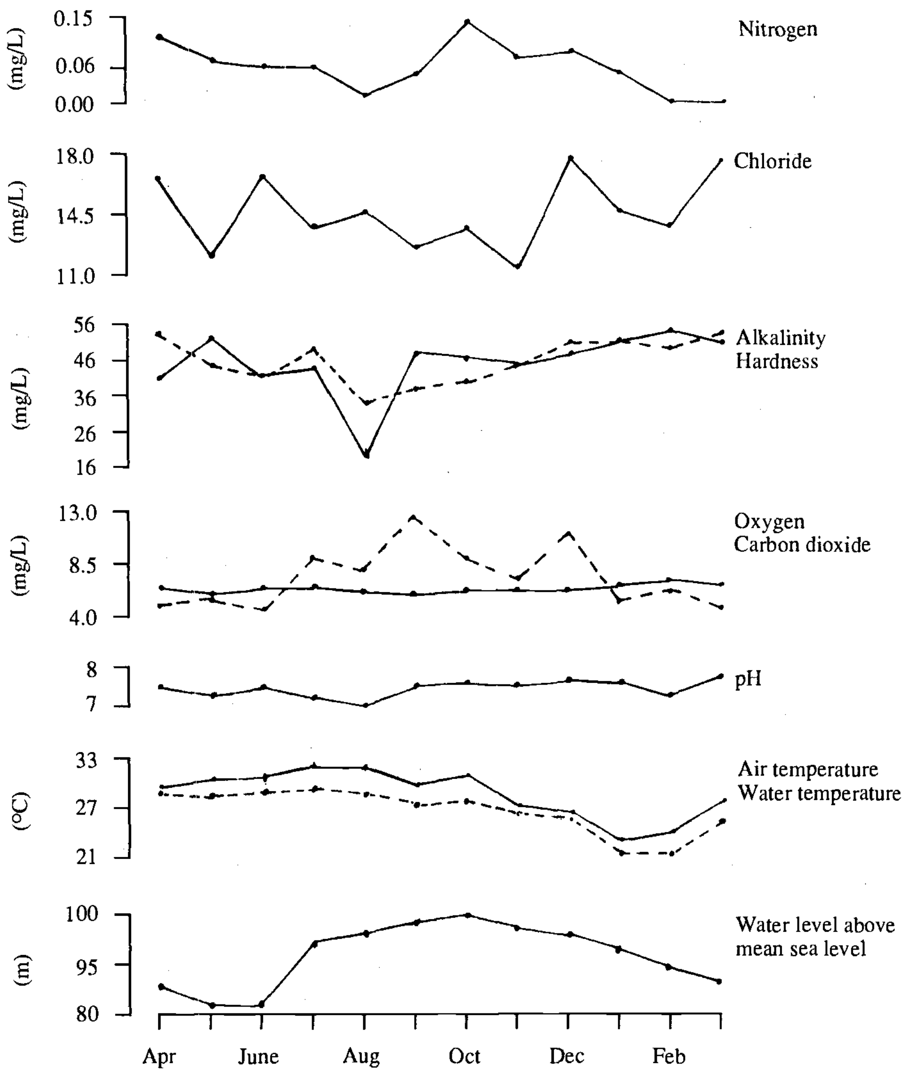

Fig. 1. Monthly variations in physicochemical parameters in Kaptai Lake (April 1988 to February 1989).

The nitrite-nitrogen fluctuated between a trace amount and 0.14 mg/L. Higher concentrations were found in April and October, whereas the trace amount was recorded in February and March.

Ammonium-nitrogen values ranged from 0.23 mg/L to 0.43 mg/L. The minimum was in September and the maximum in March. The highest and lowest concentrations of ammonium ion and free NH_3 were recorded in March and July–August, respectively.

The primary productivity of Kaptai reservoir in relation to seasonal changes in water level and transparency is presented in Table 1. The rate of gross oxygen

Table 1. Monthly variation in primary production, carbon production, organic matter production, gross energy production, and plankton biomass production in Kaptai Lake (1988–89).

Parameters	Apr	May	June	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Mean
Gross O_2 production (g/m^2 per day)	1.28	1.53	1.25	1.19	0.78	0.77	0.45	0.34	0.79	0.87	1.00	1.41	0.97
Carbon production (g/m^2 per day)	0.48	0.57	0.47	0.45	0.29	0.29	0.17	0.13	0.30	0.33	0.38	0.53	0.37
Organic matter production (g/m^2 per day)	0.88	1.06	0.86	0.82	0.55	0.53	0.31	0.23	0.55	0.60	0.69	0.97	0.67
Gross energy production (MJ/m^2 per day)	18.78	20.92	18.33	17.45	11.42	11.30	6.65	4.64	11.63	12.84	14.73	20.67	14.27
Plankton biomass (g/m^3)	4.22	5.05	4.12	3.93	2.57	2.54	1.48	1.12	2.67	2.87	3.30	4.65	3.21

production (g O_2/m^2 per day) increased from December (0.79) to May (1.53) and then declined to a minimum in November (0.34). The annual gross oxygen production ranged between 124.1 and 558.5 g O_2/m^2 per year with a mean of 354.0. Gross energy production ranged from 1 848 to 8 186 MJ/m^2 per year with an average value of 5 209 MJ/m^2 per year. The production of carbon (used in the synthesis of organic matter) ranged between 0.13 and 0.53 g C/m^2 per day, with the highest value recorded in March and the lowest in November (Table 1).

Seasonal changes in physical factors, such as reservoir level, markedly influenced the production rate. Water level showed an inverse correlation ($r = -0.88$, $p < 0.001$) with primary production. No significant correlation ($r = 0.32$) existed between Secchi disk transparency and primary production. This is similar to the findings of Pathak (1979) and Rawson (1952) who obtained an inverse relationship between mean depth and production rate. The decline in reservoir level, i.e., reservoir depth, may have caused higher concentrations of edaphic parameters giving rise to a better production rate (Larkin 1964); higher production of gross organic matter (244.6 g/m^2 per year); and an increase in plankton biomass in the reservoir (1.17 kg/m^3 per year).

Kaptai Lake productivity, according to the classification of lakes and reservoirs of Winberg (1960), seems to be mesotrophic to eutrophic.

Water temperature showed a strong positive correlation with air temperature ($r = 0.94$, $p < 0.001$). A similar correlation between air and water temperature was also reported by Macan (1958), Chowdhury and Mazumder (1981), and Patra and Azadi (1985).

Dissolved oxygen showed an inverse weak correlation with free CO_2 ($r = -0.57$, $p < 0.10$) and a positive correlation with alkalinity ($r = 0.53$, $p < 0.10$). Ruttner (1953) stated that when the CO_2 content of the trophic layer in a lake decreases because of photosynthesis, the oxygen content increases proportionally and the distribution of these two substances are exactly opposite. No significant correlation could be established between dissolved oxygen concentration and water temperature, although the highest oxygen concentration was recorded in January and February, when temperature was lowest (Fig. 1).

Water level was directly related to free CO_2 ($r = 0.74$, $p < 0.01$). An increasing trend in water level was observed during the rainy season when the maximum concentration of free CO_2 was recorded, indicating an indirect relationship between rainfall and CO_2. The high concentration of CO_2 in September may be attributed to heavy rainfall. Reid (1961) stated that rain water that percolates through soil contains CO_2 produced from organic decomposition. The influx of CO_2 in rain water is in the form of carbonic acid (Hynes 1970). Lakshminarayana (1965) also observed higher levels of CO_2 in the water during the monsoon season.

Water transparency showed a strong inverse relationship with rainfall ($r = -0.8$, $p < 0.001$) and positive and negative correlations with other factors (Table 2). A sudden decline in water transparency was noted during the monsoon period in all stations (Fig. 1). The inflow from hill streams carries suspended matter and silt, which causes a sharp rise in turbidity. Chowdhury and Mazumder (1981) and ARG (1986) also reported the occurrence of high turbidity in the lake during the monsoon period. Similar observations were made by Shafi et al. (1978) and Patra and Azadi (1985).

Table 2. Correlation matrix among the different physicochemical parameters of Kaptai Lake.

	Factors	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Water level	—														
2	Rainfall	-0.293	—													
3	Air temperature	-0.033	0.600[d]	—												
4	Water temperature	-0.081	0.503[e]	0.942[a]	—											
5	Water transparency	0.148	-0.867[a]	-0.855[a]	-0.682[c]	—										
6	Dissolved O_2	-0.279	0.141	-0.328	-0.373	0.123	—									
7	Free CO_2	0.742[b]	-0.048	0.292	0.239	-0.226	-0.570[e]	—								
8	Hardness	-0.185	-0.467	-0.561[e]	-0.529[e]	0.512[e]	0.125	-0.112	—							
9	Alkalinity	-0.324	-0.504[e]	-0.595[d]	0.457	0.562[e]	0.528[e]	-0.386	0.575[e]	—						
10	pH	-0.017	-0.454	-0.234	-0.178	0.067	-0.085	0.085	0.478	0.355	—					
11	Chloride	0.082	0.309	0.046	0.169	-0.170	0.035	0.161	-0.316	-0.037	-0.031	—				
12	Nitrite	0.314	-0.339	-0.098	0.085	0.422	-0.218	0.014	0.002	-0.041	0.340	-0.207	—			
13	Ammonium N_2	-0.319	-0.390	-0.461	-0.415	0.509[e]	0.365	-0.520[e]	0.332	0.590[d]	0.444	-0.612[d]	-0.010	—		
14	Ammonium ion	-0.034	-0.659[c]	-0.519[e]	0.804[b]	0.679	0.126	-0.239	0.494	0.415	0.594[d]	-0.410	0.135	0.819[b]	—	
15	Ammonia	-0.368	-0.535[e]	-0.485	-0.319	0.678[c]	0.401	-0.582[d]	0.415	0.691[c]	0.300	0.256	0.300	0.830[a]	0.797[b]	—

Note: Level of significance: = a = $p < 0.001$; b = $p < 0.01$; c = $p < 0.02$; d = $p < 0.05$; e = $p < 0.10$.

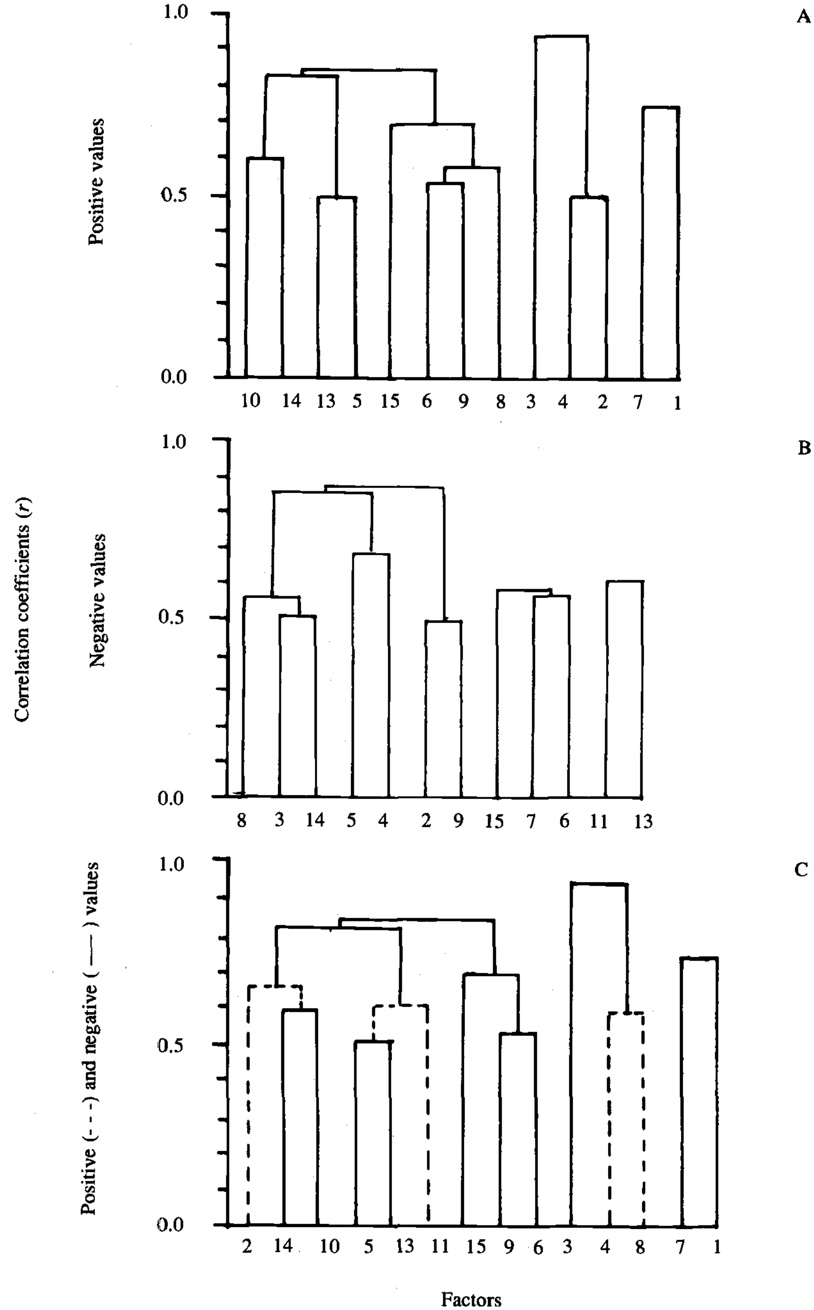

Fig. 2. Single-linkage dendrogram showing the clusters formed by various physicochemical factors. 1, water level; 2, rainfall; 3, air temperature; 4, water temperature; 5, water transparency; 6, dissolved oxygen; 7, free carbon dioxide; 8, hardness; 9, alkalinity; 10, pH; 11, chloride; 12, nitrate; 13, ammonium-nitrogen; 14, ammonium-ion; and 15, ammonia.

The only significant correlation of pH was with ammonium ion (Table 2). The recorded pH values (7.0–7.8) were close to those (7.0–7.5) obtained by Sandercock (1966) and ARG (1986), but differed considerably from those obtained by Chowdhury and Mazumder (1981).

Total hardness and alkalinity in the lake were higher during winter months and lower during the monsoon season (Fig. 1). Lakshminarayana (1965) reported a similar phenomenon from the Ganges River. A weak inversely significant correlation was found between alkalinity and rainfall ($r = -0.504, p < 0.10$). According to Mookerjee and Bhattacharya (1949), total hardness decreases due to rainfall. Lake waters registering $CaCO_3$ below 24 mg/L are generally regarded as soft (Clegg 1974).

Nitrogenous compounds in water are derived to an appreciable degree from the atmosphere, whereas ammonia is the chief decomposition product from plant and animal proteins (Ruttner 1953). A highly significant positive correlation was observed among ammonium-nitrogen, ammonium-ion, and ammonia (Table 2).

Patterns of linkage among the interacting factors are represented in Fig. 2. These diagrams were constructed by considering the correlations among the factors. From the positively correlated factors, three distinct groups were obtained: pH, ammonium-ion, ammonium-nitrogen, water transparency, ammonia, dissolved oxygen, alkalinity, and hardness formed the major group (Fig. 2A); two other groups were clustered by air temperature, water temperature, and rainfall and by free carbon dioxide and water level. Chloride and nitrite showed no positive correlation with the other factors.

Similarly, three groups were obtained from the negatively correlated factors (Fig. 2B). Water level, pH, and nitrite showed no significant negative relation with other factors. The major cluster was hardness, air temperature, ammonium-ion, water transparency, water temperature, rainfall, and alkalinity. Ammonia, free carbon dioxide, and dissolved oxygen and chloride and ammonium nitrogen formed the other two groups (Fig. 2B). Air temperature acted as an important common factor, interacting negatively with other factors. Rainfall, air temperature, water transparency, ammonium-nitrogen, ammonium-ion, and ammonia showed their dominant influence to associate with other factors in affecting the water quality.

Although the pattern of linkages shown in Fig. 2C was different from the others (Fig. 2A and 2B), the same factors were involved. Water level and free carbon dioxide were less significantly associated with other factors, and a highly significant correlation between them resulted in the formation of an isolated group (Fig. 2B and 2C). Water transparency in Kaptai Lake is significantly associated with other factors and results in direct or inverse correlations.

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Limnology and Fishery of Three Recently Impounded Reservoirs in Sri Lanka

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The hydroelectric reservoirs of Kotmale, Victoria, and Randenigala were impounded in 1985, 1984, and 1986, respectively, by damming the Mahaweli River. The surface area, maximum depth, and mean depth of the three reservoirs are 6.3 km², 78 m, 27.6 m; 23.7 km², 102 m, 30.8 m; and 23.5 km², 90 m, 36.6 m, respectively, at their full supply levels of 703, 438, and 232 m above mean sea level (MSL).

Important physicochemical factors and phytoplankton were studied by sampling of subsurface waters every 2 weeks in 12 randomly chosen stations in Randenigala and in Victoria, and in 10 stations in Kotmale over 24 months. Mean water temperature, pH, conductivity, and the total alkalinity during the study period were 25.6 °C, 6.6, 50.7 μS^{25}, and 0.31 mmol/L in Kotmale, 26.9 °C, 7.1, 77.4 μS^{25}, and 0.62 mmol/L in Victoria, and 28.3 °C, 7.4, 90.0 μS^{25}, and 0.79 mmol/L in Randenigala.

*The gill-net catches of Kotmale and Victoria are about 38 and 70 kg/ha per year, respectively. Randenigala has a fishery potential of about 70 kg/ha per year. Tilapia formed about 68%, 59%, and 69% of the catches of Kotmale, Victoria, and Randenigala, respectively. The catch at Kotmale was mainly Java tilapia (*Oreochromis mossambicus*) and Nile tilapia (*O. niloticus*), whereas at Victoria and Randenigala it was mainly Java tilapia. Indigenous species constituted only about 10% of the catch.*

Reservoir fishery is an important component of the inland fisheries in South and Southeast Asia. It is especially important for Sri Lanka, which has no natural lakes but contains a large number of irrigation reservoirs, varying in size from <10 ha to >7 000 ha, and providing a surface area of 176 000 ha (De Silva 1988). The exact number of reservoirs in Sri Lanka is not known, but is estimated at between 3 500 and 10 000 (Abeywickrema 1955; Mendis 1977). Most of these shallow reservoirs were created before the 12th century and are concentrated in the dry zone in the northwestern, northern, and eastern lowland areas of the country.

Recently, several deep reservoirs have been created, mainly for hydroelectric purposes, by damming the country's longest river, the Mahaweli. Three of these reservoirs, Kotmale, Victoria, and Randenigala, are situated in the uplands, between 200 and 700 m above mean sea level (MSL).

The limnology and the fishery of many low-level irrigation reservoirs have been studied (Mendis 1965; Amarasinghe et al. 1983; Chakrabarty and Samaranayake

1983; Schiemer 1983; De Silva 1985). However, only a few studies are available from upland deep reservoirs in Sri Lanka (de Silva and Somarathna 1990).

This paper presents the state of the fishery and the limnologic aspects important for the fishery of Kotmale, Victoria, and Randenigala reservoirs.

Materials and Methods

Kotmale hydroelectric reservoir is an inverted L-shaped reservoir created by impounding one of the major tributaries of the Mahaweli, the Kotmale Oya.

The Victoria reservoir dam is built just downstream of the point of confluence of the main branch of the Mahaweli and a major tributary, the Hulu. As a result, a W-shaped reservoir has been created with the Mahaweli and Hulu joining at the two ends of the outer limbs of the reservoir. The reservoir receives its water mostly from the Hulu because water from the Mahaweli is usually diverted upstream of the reservoir to the dry-zone reservoirs.

Randenigala reservoir, a hatchet-shaped hydroelectric reservoir, is the third reservoir of the Mahaweli and is situated immediately downstream of the Victoria reservoir. Although several streams flow into it, its main supply of water comes from the Victoria reservoir, which, therefore, mostly controls the water level of the reservoir.

The three reservoirs have steep banks and, as a consequence, the littoral zone is very narrow along most of the shoreline. Frequent fluctuations of water level, caused by high draw-down for power generation, frequently change the position and extent of the reservoir littoral.

Major morphometric and hydrological features of the three reservoirs are listed in Table 1. Important physicochemical characteristics (temperature, pH,

Table 1. Some important morphometric features of Kotmale, Victoria, and Randenigala reservoirs.

	Kotmale	Victoria	Randenigala
Year of impoundment	1985	1984	1986
Storage (10^6 m^3)	174	722	860
FSL (m above MSL)[a]	703	438	232
Surface area at FSL (km^2)	6.3	23.7	23.5
Catchment area (km^2)	544	1 891	2 333
Maximum depth (m)	78	102	90
Mean depth (m)	27.6	30.8	36.6
Shore line (km)	32	115	73
Shore line development factor	3.96	6.66	4.25
Catchment area to reservoir area	86.35	79.8	99.28
Littoral zone at FSL (<3 m depth) (km^2)	0.38	1.6	0.96
Lowest draw-down level (m above MSL)	665	370	203
Useful storage capacity (10^6 m^3)	152	688	565
Dead storage capacity (10^6 m^3)	22	34	295
Surface area at dead storage (km^2)	1.56	1.8	13.0

[a] FSL = full supply level; MSL = mean sea level.

conductivity, dissolved oxygen concentration, total alkalinity, turbidity, and Secchi disk transparency) were studied in 10 randomly selected stations in Kotmale and in 12 stations in both Victoria and Randenigala. Samples were taken every 2 weeks during the period January 1988 to December 1989. Subsurface phytoplankton was sampled quantitatively using an Apstein net with an attached flowmeter.

Fishing was allowed only after January 1989 in Victoria and after July 1989 in Kotmale, but some illegal fishing was done earlier. Ten fibreglass outrigger canoes now operate in Kotmale and 28 similar canoes operate in Victoria. The catch was monitored once a month from September 1989 to April 1990 in Kotmale and from January 1989 to April 1990 in Victoria.

Fishing is still not permitted in Randenigala because the reservoir is situated within the boundaries of a wildlife sanctuary. However, illegal fishing started from the year of impoundment. Despite the difficulties encountered in meeting the fishermen because of the illegal nature of fishing, the catch was monitored at least once a month during August 1989 to April 1990.

Results

Water levels, surface areas, and average depths of the three reservoirs are given in Table 2. The littoral area, taken as the area that is less than 3 m deep, is only 6.1% of the total area at full supply level (FSL) in Kotmale, 6.6% in Victoria, and 4.1% in Randenigala. The frequent fluctuations of water level continuously changed the position and extent of the littoral. The average surface areas during the study period were only 59% of the area at FSL in Kotmale, 61% in Victoria, and 74% in Randenigala.

The important physicochemical parameters of subsurface waters in the three reservoirs are given in Table 3. Monthly changes in temperature, pH, and conductivity are given in Fig. 1.

Aquatic macrophytes, floating or rooted, were not observed in any of the reservoirs, and the primary productivity of all three reservoirs is almost entirely due to phytoplankton. Subsurface phytoplankton flora of all three reservoirs are dominated by Chlorophyta, by abundance as well as by the number of taxa. Desmids were the most common and among them the genera of *Staurastrum* and *Cosmarium*.

The catch in both Victoria and Randenigala is dominated by *O. mossambicus*, which is more common in Randenigala (Fig. 2). Nile tilapia is sparse in Randenigala, but is as common as Java tilapia in Kotmale. Indigenous species, of which the most important is *Barbus sarana*, constituted only 10.5%, 12.2%, and 9.3% of the respective catches in Kotmale, Victoria, and Randenigala.

The mean sizes of major species in the catch of the three reservoirs are given in Table 4.

Carnivorous fish species were not present in the Kotmale catch, although it is known that the catfish, *Ompok bimaculatus*, and the goby, *Glossogobius giuris*, are present (unpublished data). The major carnivores present in Victoria are *O. bimaculatus*, *G. giuris*, *Channa marulius*, and *Anguilla nebulosa*, of which only *O. bimaculatus* is present in significant numbers. *O. bimaculatus*, *G. giuris*,

Table 2. Annual maximum, minimum, and mean water level; surface area; and average depth of Kotmale, Victoria, and Randenigala reservoirs for the period January 1987 to December 1989.

	Water level (m above MSL)[a]			Surface area (ha)			Mean depth (m)		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Kotmale									
1987	645.26	701.48	668.39	30	590	200	8.4	26.5	14.2
1988	675.46	702.56	691.50	262	615	459	15.2	27.2	21.7
1989	648.30	703.02	687.04	42	630	431	9.0	27.6	21.0
1987–89	645.26	703.02	682.31	30	630	369	8.4	27.6	19.0
Victoria									
1987	377.94	423.20	396.27	285	1 570	705	19.5	27.4	23.4
1988	404.65	437.84	419.90	775	2 340	1 415	25.6	30.8	27.5
1989	409.13	438.09	429.68	920	2 370	1 900	25.9	30.8	29.1
1987–89	377.94	438.09	415.29	285	2 370	1 341	19.5	30.8	26.7
Randenigala									
1987	197.07	217.82	206.03	1 080	1 860	1 417	21.8	30.2	25.3
1988	203.12	219.82	212.16	1 310	1 930	1 650	24.1	30.1	27.8
1989	213.72	230.71	225.10	1 080	2 310	2 117	21.8	36.1	33.4
1987–89	197.07	230.71	214.43	1 080	2 310	1 728	21.8	36.1	28.8

[a] MSL = Mean sea level.

Table 3. Important physicochemical parameters of subsurface waters of Kotmale, Victoria, and Randenigala reservoirs.

	Kotmale			Victoria			Randenigala		
	Min	Max	Mean	Min	Max	Mean	Min	Max	Mean
Temperature (°C)	24.0	27.6	25.6	25.2	24.8	26.9	26.2	30.6	28.3
pH	6.08	7.19	6.61	6.68	7.82	7.13	7.1	7.72	7.40
Conductivity (μS^{25})	40.2	54.3	50.7	53.1	92.2	77.4	78.0	99.3	90.1
DO (mg/L)[a]	7.47	8.90	8.18	5.91	8.90	7.45	6.40	8.80	7.35
Alkalinity (mmol/L)[a]	0.23	0.43	0.31	0.45	0.82	0.62	0.68	0.97	0.79
Turbidity (NTU)[a]	2.10	3.90	2.94	2.07	3.61	2.75	1.27	3.19	2.19
Secchi disk depth (m)	1.70	2.53	1.97	1.31	2.84	2.08	1.96	3.42	2.75
Morphoedaphic index	1.45	3.62	2.21	1.72	3.60	2.76	2.13	3.55	2.98

[a] DO = dissolved oxygen concentration; alkalinity = total alkalinity; NTU = nephalometric turbidity units.

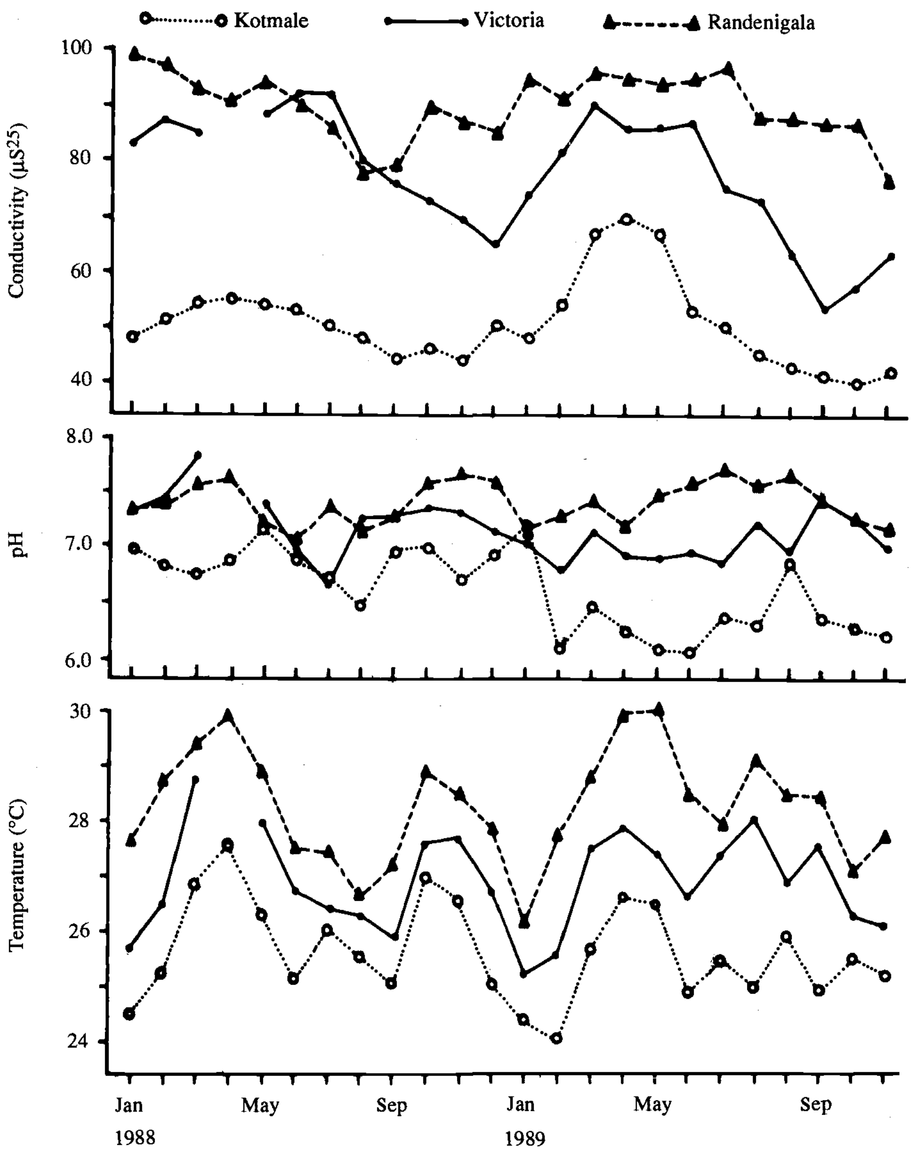

Fig. 1. Monthly changes in temperature, pH, and conductivity of subsurface waters in Kotmale, Victoria, and Randenigala reservoirs.

C. marulius, and *A. nebulosa* are the carnivores present, albeit in small numbers, in Randenigala.

The main fishing gear in all three reservoirs is the gill net. Usually, three to six pieces of net, each about 50–75 m long and 1.5–2.0 m deep, are set from a canoe operated by two people. Fishermen in Kotmale use 2-inch (5-cm) stretched mesh nets, although it is illegal to use nets with a mesh size below 4 inches (10 cm).

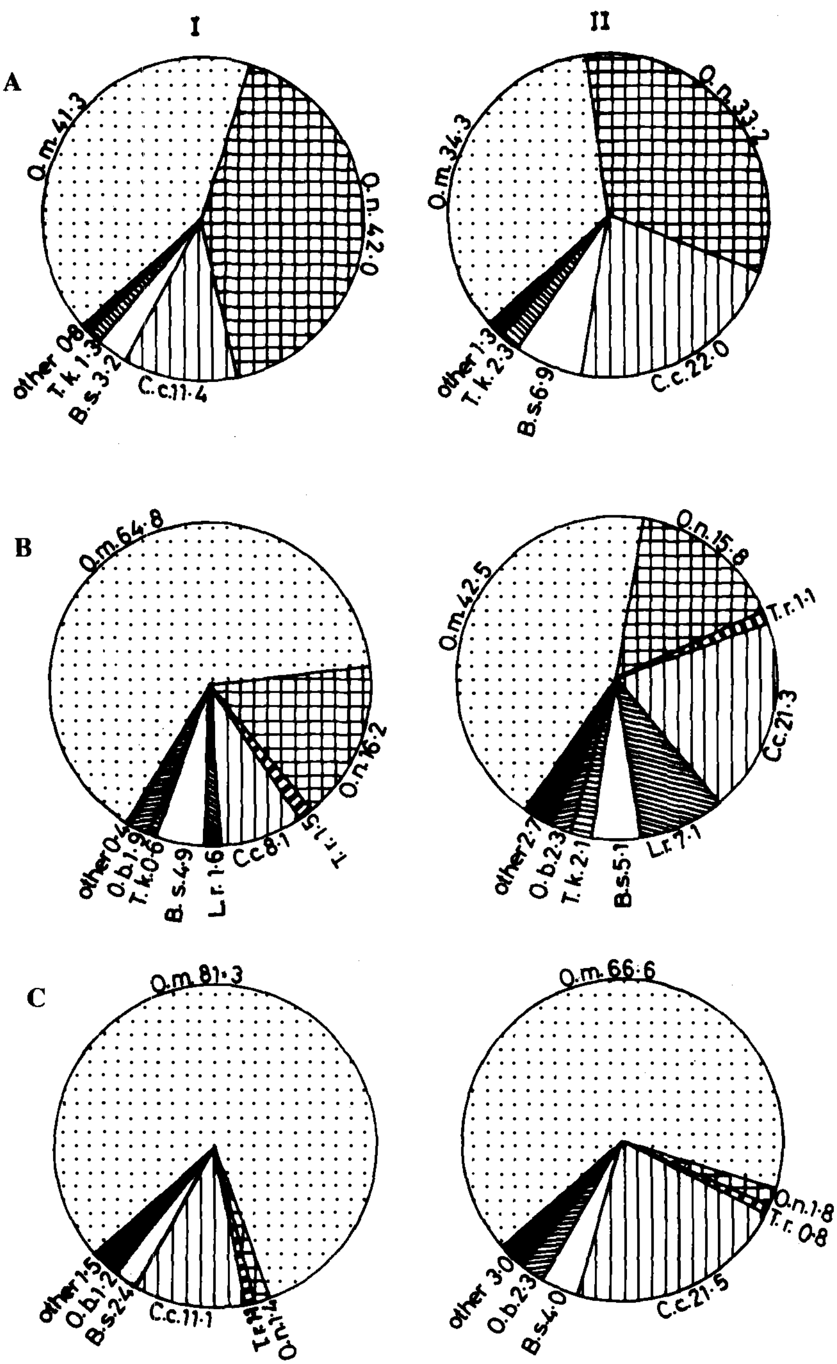

Fig. 2. Catch composition (I) by number and (II) by weight at (A) Kotmale; (B) Victoria; and (C) Randenigala reservoirs. (*B.s.* — *Barbus sarana*; *C.c.* — *Cyprinus caprio*; *L.r.* — *Labeo rohita*; *O.b.* — *Ompok bimaculatus*; *O.m.* — *Oreochromis mossambicus*; *O.n.* — *Oreochromis niloticus*; *T.k.* — *Tor khudree*; *T.r.* — *Tilapia rendalli*).

Table 4. Mean ± standard error of the size (cm) of major fish species caught in the three reservoirs.[a]

Species	Kotmale	Victoria	Randenigala
Oreochromis niloticus	17.4 ± 0.05 (1 032)	25.7 ± 0.08 (858)	23.6 ± 0.53 (21)
O. mossambicus	17.8 ± 0.30 (1 015)	22.2 ± 0.05 (2 534)	21.6 ± 0.07 (1 225)
Tilapia rendalli	21.2 ± 0.29 (92)	20.8 ± 0.74 (16)	
Cyprinus carpio	23.5 ± 0.25 (279)	30.4 ± 0.39 (402)	28.8 ± 0.28 (167)
Labeo rohita	49.9 ± 1.74 (36)		
Barbus sarana	24.6 ± 0.24 (70)	29.1 ± 0.35 (84)	26.9 ± 0.72 (36)
Tor khudree	26.8 ± 0.83 (33)	47.8 ± 6.25 (10)	
Ompok bimaculatus	39.6 ± 0.49 (42)	40.7 ± 0.49 (18)	

[a] The number of fish examined is given in parenthesis.

Fishermen in Victoria and Randenigala use nets of stretched mesh size 4 inches (10 cm) and above. This is reflected in the size of fish caught (Table 4).

In Victoria, 28 fibreglass and about 30 dugout outrigger canoes operate. On average, each craft operates 20–25 days per month (250–300 days per year). The catch of both types of craft is similar. Average daily catch per craft, which can be considered as the catch-per-unit-effort (CPUE) (De Silva 1988), varied from month to month from 5.4 to 14.2 kg with an average of 10.4 kg during the study period. The annual production of the reservoir can be estimated from the CPUE as 166.2 t, because the number of craft operating is 58 and each craft operates for an average of 275 days per year. This is equivalent to 70 kg/ha. The average catch per day is 455 kg.

Ten fibreglass canoes operate on average for about 250 days per year in Kotmale. From 183 samples (craft-days) spread over an 8-month period, CPUE (per craft) was estimated as 9.42 kg. Thus, the annual yield can be estimated as 23.6 t or 38 kg/ha. The daily yield from the reservoir is only 64.5 kg.

Only eight dugout canoes apparently operate in Randenigala reservoir. Because these operate illegally, it was difficult to monitor the catch. However, data from 54 craft-days over a period of 7 months indicate a CPUE (per craft) of 13.1 kg. Each craft apparently operates for about 25 days per month; therefore, the annual production can be calculated as 39.2 t (16.7 kg/ha). This is obviously an underestimate of the potential of the reservoir because:

- The fishermen operate for only 2–4 hours each night, compared to overnight fishing in other reservoirs;
- Only one or two gill nets are usually set from each craft; and
- The number of crafts operating in the reservoir is far below the optimum number when compared with that of the other reservoirs.

Discussion

Lowland perennial reservoirs in Sri Lanka appear to have a higher nutrient content, based on their respective conductivities, than upland reservoirs. Lowland reservoirs have conductivities ranging from 155 to 925 µS (De Silva 1988) in comparison with the low conductivities of Kotmale, Randenigala, and Victoria reservoirs.

Thus, a low fish yield per hectare could be expected from a deep upland reservoir, when compared with a shallow lowland reservoir. Although it is too early to come to a firm conclusion regarding the fish yield of these newly built reservoirs, the estimated yield of 38 kg/ha per year from Kotmale is lower than the lowland perennial reservoirs (De Silva 1988), and the yield from Victoria (70 kg/ha per year) is only higher than that obtained only from Hurulu Wewa reservoir (40 kg/ha per year) among the lowland reservoirs.

Oglesby (1985) estimates the average fish yield in tropical lowland lakes and reservoirs at about 80 kg/ha per year. Sreenivasan and Thayaparan (1983) predicted that the fish yield from Victoria reservoir would be 170 t/year (or 75 kg/ha per year). These estimates are remarkably close to the observed yield from Victoria, although the yields of almost all lowland perennial reservoirs in Sri Lanka are much higher (258–283 kg/ha per year, according to De Silva 1988) than Oglesby's estimate.

Sreenivasan and Thayaparan (1983) predicted the annual fish yield from Kotmale and Randenigala would be 150 kg/ha. However, Randenigala appears to have a higher fishery potential than Victoria because it has a higher conductivity, a higher morphoedaphic index (MEI), and a higher ratio of catchment area to reservoir area.

Physicochemical parameters in the three reservoirs tend to increase in temperature, pH, conductivity, MEI, and alkalinity downstream. Although the pH of lowland perennial reservoirs in Sri Lanka is either neutral or slightly alkaline (De Silva 1988), Kotmale is slightly acidic. The total alkalinity of Kotmale, Randenigala, and Victoria is less than 1.0 in contrast to that of the lowland reservoirs, which have alkalinities >1.0 (De Silva 1988). High HCO_3^- alkalinity is known to precipitate bivalent cations such as Ca^{2+} and Mg^{2+} making them unavailable to food chains; however, the alkalinities in Kotmale, Randenigala, and Victoria are too low for such an effect to occur.

The freshwater fishery of Sri Lanka is dominated by the exotic *O. mossambicus*, which was introduced in 1952 (Fernando and Indrasena 1969; De Silva 1983; Fernando and De Silva 1984). *Ompok mossambicus* dominates the lowland reservoir fishery and constitutes 60–100% of the total catch of individual reservoirs, with the exception of the fisheries in Sorabora Wewa and Mahagama where the dominant species are *O. niloticus* and *Tilapia rendalli*, respectively (De Silva 1988). The fisheries of Victoria and Randenigala, although of recent origin, are no exception.

The partial dominance of Nile tilapia in Kotmale, but not in either Victoria or Randenigala, poses an interesting situation. The only reservoir in Sri Lanka in which Nile tilapia has been shown to be dominant is Sorabora Wewa (Chandrasoma 1986). Here, from 1979 to 1982, the stocked Nile tilapia almost completely replaced the Java tilapia that had been present. The success of the Nile tilapia in this reservoir has been attributed to the dominance of blue-green algae in its phytoplankton and the ability of Nile tilapia to use this food source effectively (Chandrasoma 1986), although it has been pointed out that Java tilapia can also use blue-green algae, albeit not as effectively as the former species (De Silva 1988). In the three upland Mahaweli reservoirs, the ratio of Java tilapia to Nile tilapia increases with decreasing elevation. The ratios in Kotmale (situated 703 m above

MSL), Victoria (438 m above MSL), and Randenigala (232 m above MSL) are 1:1, 3:1, and 59:1, respectively. The phytoplankton profile in Kotmale is similar to that in Randenigala and Victoria, with Cholorophyta dominating. The success of Nile tilapia in Kotmale does not seem to depend on the abundance of blue-green algae in the reservoir because the relative abundance of blue-green algae in Kotmale is not significantly different from that of the other two reservoirs. However, Nile tilapia can tolerate a lower temperature than Java tilapia (Balarin and Hatton 1979). Because the temperature of Kotmale is lower than the temperature of the other two reservoirs, the temperature tolerance of Nile tilapia may contribute to its success there.

De Silva (1988) showed that the total yield (Y_t) as well as the CPUE (per craft) of Sri Lankan lowland reservoirs are significantly related to the surface area (A) of the reservoirs:

[1] $Y_t = 0.116A + 200.54$ ($p < 0.01$)

and

[2] $\text{CPUE} = 0.0017A + 5.524$ ($p < 0.01$)

According to these relationships, the annual total yield and CPUE of Kotmale, Victoria, and Randenigala could be predicted as, respectively, 273.6, 475.5, and 473.1 t (434.3, 200.6, and 201.3 kg/ha) and 6.6, 9.6, and 9.5 t/boat per year (18.07, 26.17, and 26.08 kg/boat per day). These predictions appear to be much higher than can reasonably be expected from upland reservoirs, and in fact are much higher than the observed yields and CPUE of Kotmale and Victoria.

The number of craft operating in the lowland reservoirs varies from one per 151 ha (Lunugamwehera, a newly impounded reservoir of 3 023 ha) to one per 9 ha (Pimburettewa, a highly productive reservoir of 843 ha) (De Silva 1988). A significant relationship appears to exist between the number of craft operating (B) and surface area of the reservoir (A):

[3] $B = 1.0261A^{0.4956}$ ($r^2 = 0.27, n = 20, p < 0.05$).

According to this relationship, the number of craft in Victoria, Kotmale, and Randenigala should be 48, 25, and 48, respectively. De Silva's (1988) relationships between yield and area, and CPUE and area, which are derived from the same data base, predict the number of craft that could be effectively operated in the three reservoirs as 50, 41, and 50, respectively. The number of craft now operating in Victoria exceeds the predicted number by about 10, whereas, in the other two reservoirs, the number of craft operating is below the predicted number. It may be that the optimum number of craft is already operating in Victoria, but the fisheries of Kotmale and Randenigala could be improved significantly.

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Limnology and Fisheries of Some South Indian Reservoirs

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The physicochemical and morphometric features of some of the reservoirs in Tamil Nadu are described. Generally stable thermal stratification does not occur in reservoirs south of 17 °N. The dissolved oxygen regime is an indicator of the trophic status of the reservoirs; those reservoirs with hypolimnial oxygen deficits are usually productive. The carbon dioxide system shows variations indicative of the metabolism of reservoir waters. More productive reservoirs show greater bioactivity. Four reservoirs with lower primary production (P_g) ranked lowest in fish yields, whereas those with higher P_g did not give higher fish yields. Energy conversion was highest in Palar Porandalar, where the fish yield was 170 kg/ha per year. Predator-dominated reservoirs gave lower conversions than carp-dominated reservoirs. Regular stocking raised fish yields.

The objectives of fishery management programs are threefold: first, to estimate potential fish yields and compare them with the existing harvest; second, to increase fish yield, if feasible; and, third, to manage specific fisheries with relevance to economic, social, and biological factors (Oglesby 1985). Limnological information is a useful predictive tool and is valuable when formulating management policies (Larkin 1964; Kitaka 1972). Fisheries management has been defined as the art and science of producing annual crops of wild fish for recreational and commercial uses (Bennett 1962). Stretching this further, we may include "culture of fish" in a reservoir as management.

Indices of Productivity

A relationship between alkalinity and fish production was established by Ball (1948) and a correlation between bicarbonate and fish production was noted by Waters (1957). Barrett (1953) and Moyle (1954) found that productivity was higher in hard waters than in soft waters. Northcote and Larkin (1958) found fish production to be proportional to total dissolved solids (TDS). Carlander (1955) and Slack (1955) observed a positive correlation between methyl-orange alkalinity and standing crop of fish. Chacko and Ganapati (1949) stated that a minimum of 650 ppm calcium carbonate is essential for good fish production. Among physical features (morphometry), mean depth and fish yields have been correlated by Rawson (1952, 1955). Total mineral content, electrical conductivity (EC), and TDS were deemed to be important parameters in estimating the productivity of lakes (Rawson 1951).

Using the deductions of Rawsons (1951, 1952) and Northcote and Larkin (1956), Ryder (1965) formulated the morphoedaphic index (MEI) as a fish-yield estimator for Canadian lakes and later extended it to tropical reservoirs:

[1] MEI = TDS/MD or EC/MD

where TDS = total dissolved solids (mg/L), EC = electrical conductivity (μmho/cm), and MD = mean depth (m).

The use of MEI in ecosystems such as reservoirs does have limitations, however. McConnell et al. (1977) used gross photosynthesis as an estimator of fish production. Oglesby (1977) and Melack (1976) also found this to be more appropriate than MEI, especially for tropical lakes. Earlier, I used gross photosynthesis to assess the possible yields from reservoirs (Sreenivasan 1964a, b) and the concept of energy transfers to predict fish yields (Sreenivasan 1972).

Physicochemical Features

The morphometric features and chemical parameters of selected reservoirs are given in Tables 1 and 2.

Thermal Features

As a rule, thermal stratification is either nonexistent or rare and ephemeral in these reservoirs (Table 3). However, exceptions were noted in Pilloor reservoir (maximum depth 74 m) and Sholiar (maximum depth 81 m).

A striking feature of these deep tropical reservoirs is the high bottom temperature. Except in the uplands, the minimum bottom temperature was 21.5°C (Amaravathy) (Table 4). In the upland reservoir, Sandynulla, it was 15.1°C, and in Pykara it was 18.0°C. In these two reservoirs, thermal stratification was noted very rarely and, when observed, it was unstable. The thermocline was hardly 1 m deep and was mostly at the bottom. This is in contrast with the more striking and sharp thermal stratification in upland lakes such as Ooty Lake and Kodaikanal Lake (Sreenivasan 1968, 1964a). The maximum difference between the surface and bottom temperatures among all the reservoirs was noted in Bhavanisagar (4.6°C). The smallest difference was in Uppar (0.7°C) — a shallow well-mixed reservoir.

In the Andhra Pradesh reservoirs, Nagajunasagar (16°34′ N) and Tungabhadra (16°15′ N), thermal stratification did not occur. In northern India, in Govindsagar, Rihand, Getalsud, etc. (24°01′ to 30°25′ N) thermal stratification occurred. The dividing line for thermal stratification seems to be 17° N.

Resistance to mixing or relative thermal resistance (RTR) was high in most of the reservoirs. It was 35–135 units in Mettur, 69–160 in Bhavanisagar, 42–73 in Tirumoorthy, and 200 in Pechiparai. More than wind power, it is the inflow of water that keeps the water mixed.

Table 1. Morphometric data of some south Indian reservoirs.

Reservoir	Water spread at FRL[a] (ha)	Gross capacity at FRL ($m^3 \times 10^6$)	Depth (m) Max	Depth (m) Mean	Volume development	Catchment area (km^2)	Elevation above MSL[b] (m)
Stanley (Mettur Dam)	14 690	2 646	37.0	17.0	1.4	41 728	243
Bhavanisagar	7 875	92.9	36.6	11.9	1.0	4 150	280
Vaigai	2 420	193.1	28.3	8.1	0.8	—	916
Sathanur	1 255	190.3	30.2	10.0	1.0	—	213
Krishnagiri	1 250	68.3	17.0	5.2	0.94	537	483
Vidur	773	16.93	9.8	2.1	0.68	1 283	38
Amaravathy	850	11.3	35.0	13.7	1.2	870	358
Sandynulla	258	20.28	24.7	10.3	5.3	111	2 123
Pykara	448	59.69	36.6	14.5	1.2	250	2 036
Aliyar	648	107.0	41.0	16.8	1.2	195	320
Pechiparai	1 515	136.4	33.7	8.4	0.75	205	92
Tirumoorthy	466	51.0	32.0	11.0	1.0	79	407
Sholiar	553	144.3	81.0	26.4	—	120	370
Pilloor	389	44.4	74.0	11.4	—	118	920
Uppar	440	16.37	14.6	3.64	—	893	860
Palar Porandalar	512	43.15	19.85	8.43	1.27	346	320
Manjalar	197	13.48	17.4	6.84	1.18	305	289
Manimuthar	940	146.1	36.0	16.8	1.2	415	320

[a] FRL = full reservoir level.
[b] MSL = mean sea level.

Table 2. Some important chemical parameters of select south Indian reservoirs (range in parentheses).

Reservoir	Gross primary production (g O_2/m^2 per day)	TOC (mg/L)	Kjeldahl N (mg/L)	MOA (mg/L)	Total hardness ($CaCO^3$) (mg/L)	EC (µmho/cm)	Chloride (mg/L)	Silicate (mg/L)
Stanley	6.20 (1.05–10.97)	8.77 (5.30–12.0)	3.36 (0.56–5.80)	105 (75–228)	110 (74–128)	210 (130–300)	22 (11–37)	0.0–19.9
Bhavanisagar	6.21 (1.73–13.50)	6.6 —	4.88 (2.70–10.50)	60 (55–83)	55 (26–112)	120 (48–200)	14 (9–30)	0.0–15.1
Sathanur	6.17 (1.81–14.20)	9.17 (3.60–12.60)	4.53 (1.66–7.64)	286 (264–672)	158 (112–264)	420 (320–800)	46 (18–66)	0.1–15.1
Amaravathy	13.7 (0.30–18.3)	18.2 (12.80–21.60)	2.60 (1.68–2.80)	25.86 (7–42)	38 (30–50)	48 (38–63)	6 (4–10)	1.4–38.5
Uppar	6.6	15.4	1.68	318	—	375	44	—
Manjalar	6.7 —	8.7 —	17.92 —	140 (32–224)	109 (44–174)	245 (55–500)	14 (6–30)	—
Krishnagiri	4.27 (0.15–14.20)	8.18 —	6.3 (5.60–7.00)	239 (190–558)	120 (76–146)	350 (250–405)	23.8 (12–33)	0.32–4.4 0.32
Vaigai	8.47 (1.00–16.20)	—	—	— (79–247)	7.4 —	208 (125–300)	13.0 (10–23)	0.0–9.7

Aliyar	4.98 (2.0–10.0)	8.86 (4.0–13.80)	0.82 (0.34–1.12)	40 (15–70)	24 (14–30)	50 (32–300)	6 (4–20)	0.5–18.0
Tirumoorthy	10.76 (0.50–3.48)	7.46 (7.20–14.56)	3.75 (0.95–8.96)	45 (16–121)	29 (16–44)	80 (40–140)	1.8	1.9–6.2
Manimuthar	1.86 (1.80–6.30)	— (12.47–13.20)	— (4.48–5.60)	18.15 (10.28)	18.15 (7–16)	10.6 (29–80)	826 (4–14)	1.6–5.7
Sandynulla	6.04 (2.20–9.80)	17.31 (12.00–22.6)	8.24 (2.10–15.00)	35 (12–62)	41.6 (28–56)	160 (100–280)	29.4 (12.0–18.5)	0.0–4.7
Pykara	ND —	10.40 (7.20–13.35)	3.36 —	10 (6–18)	8 —	25 (18–100)	15 (10–18.2)	—
Pechiparai	2.78 (1.24–5.20)	5.46 (3.00–9.00)	5.00 (3.92–6.16)	13.6 (10–18)	15 (12.18)	44 (25–69)	7.3 (6–14)	1.8–24.0
Palar Porandalar	ND	7.52	ND	45.0	14.5	70	10.0	5.2

Note: ND = not determined; — = not available; TOC = total organic carbon; MOA = methyl-orange alkalinity.

Table 3. Maximum difference in surface and bottom values of various parameters in different reservoirs.

	Temperature (°C)	pH	DO (mg/L)	MOA (ppm)
Tirumoorthy	2.6	1.4	1.0	36
Bhavanisagar	4.6	2.5	8.0	71
Pilloor	4.2	2.6	7.4	21
Sholiar	2.2	0.5	8.2	12
Aliyar	3.2	2.3	9.2	38
Stanley	3.7	1.5	8.8	80
Sathanur	3.0	0.8	7.0	78
Krishnagiri	3.4	0.9	7.6	74
Amaravathy	3.0	3.0	10.0	33.2
Sandynulla	3.0	2.5	8.8	67
Pykara	3.0	0.6	6.2	3.5
Uppar	0.7	0.4	6.0	56
Vaigai	3.4	1.5	?	50

Note: DO = dissolved oxygen; MOA = methyl-orange alkalinity.

Table 4. Thermal properties of various reservoirs.

	Surface		Bottom		
Reservoir	Max	Min	Max	Min	Thermal stratification
Aliyar	32.8	26.0	31.0	24.2	Very rare, ill defined
Pechiparai	32.0	24.5	24.9	22.0	Regular, stable
Stanley	32.0	24.2	30.0	24.0	Rare, unstable
Krishnagiri	31.4	23.5	28.0	23.0	Very rare, ill defined
Bhavanisagar	31.0	23.8	30.2	22.2	Very rare, unstable
Sathanur	30.4	25.0	28.5	24.0	Nil
Pilloor	29.6	26.0	—	—	Stable
Amaravathy	28.8	24.0	27.0	21.5	Nil
Pykara	22.6	19.0	20.1	18.0	Occasional
Sandynulla	22.6	16.4	20.0	15.1	Rare

Dissolved Oxygen Regime

A skillful limnologist can probably learn more about the nature of a lake from a series of oxygen determinations than from any other kind of chemical data (Hutchinson 1957). This seems to be true in ponds and lakes, where both diurnal and vertical variations are common. In reservoirs, especially large ones, vertical changes are important, but diurnal changes are not sharp enough for interpreting bioactivity. Hypolimnial oxygen deficits were considered to indicate productive waters (Thienemann 1928).

A comparison of Tables 3 and 5 indicates that large differences in dissolved oxygen (DO) between the surface and bottom occur in productive reservoirs: Amaravathy (10.0 mg/L), Sandynulla (8.8 mg/L), Aliyar (9.2 mg/L), Mettur

Table 5. Morphoedaphic index (MEI) and fish production.

Reservoir	MEI	Fish yield Range (t)	Average total (t)	Average area basis (kg/ha)
Uppar[a]	103.0	5.6–120.4	34.6	78.7
Krishnagiri[b]	67.3	8.4–55.4	26.9	21.5
Sathanur[c]	42.0	52.8–214.4	142.0	113.1
Manjalar[c]	36.0	4.2–39.3	25.4	128.7
Amaravathy[d]	30.2	20.9–427.1	104.6	123.0
Vaigai[b]	25.7	4.8–60.2	21.6	8.9
Mettur (Stanley)[c]	12.4	145.7–628.8	346.6	23.6
Bhavanisagar[d]	10.1	66.9–342.7	184.8	23.5
Palar Porandalar[a]	8.3	13.1–176.4	87.2	170.4
Tirumoorthy[d]	7.3	5.2–25.5	13.3	28.5
Pechiparai[b]	5.2	0.8–17.1	6.4	4.2
Manimuthar[b]	3.1	1.8–12.0	6.4	6.9
Aliyar[d]	3.0	3.8–62.5	18.7	28.8

[a] 12-year average.
[b] 18-year average.
[c] 19-year average.
[d] 20-year average.

(8.8 mg/L), Bhavanisagar (8.0 mg/L), Sathanur (7.0 mg/L), and Krishnagiri (7.6 mg/L). Even in the shallow Uppar, there was a difference of 6.0 mg/L. Surprisingly, in Tirumoorthy, it was only 1.0 mg/L, whereas, in Pykara, a reservoir considered oligotrophic, it was 6.2 mg/L (after enrichment from gelatin-factory effluents and inflow from the Sandynulla reservoir, although earlier studies showed mostly orthograde oxygen curves (Sreenivasan 1968).

Apart from indicating the trophic status of the reservoir (and hence the fishery potential), the oxygen regime also aids fishing operations. Generally, fish movements are constrained by lower oxygen content because fish prefer well oxygenated layers. A knowledge of the vertical distribution of oxygen in the reservoirs would, therefore, help the operators to lay the gill nets at appropriate depths.

Despite the depletion of oxygen in the hypolimnion of the reservoirs, the bottom water that is discharged through low level outlets is reoxygenated within 50 m downstream, making this water suitable for fish life.

Amaravathy reservoir has a high fish production (Sreenivasan 1980, 1988). In this reservoir, not only was the clinograde oxygen curve very common, but also complete depletion of oxygen was accompanied by the production of H_2S in the summer. Photosynthetic oxygen production was very high on some occasions (56.91 g O_2/m^2 per day gross; 6.77 g O_2/m^2 per day net) and respiration was 50.14 g O_2/m^2 per day (Sreenivasan 1965). Primary production was high in the reservoir (Table 2). For the East Lake in China, Jiang (1984) recorded oxygen production of 6–7 g O_2/m^2 per day. Occurrence of H_2S was also noted in Bhavanisagar, Mettur, and Sathanur along with hypolimnial oxygen depletion. In

Sholiar, oxygen deficits also were noted, and were partly due to nonbiological factors, such as the presence of iron (increasing from surface to bottom).

In Pechiparai, the very high iron content (26.0 mg/L) was responsible for a permanent anoxic bottom (iron meromixis). Primary production was low. Dense algal populations (sometimes in bloom proportions) in reservoirs like Amaravathy, Aliyar, Bhavanisagar, and Mettur produced higher oxygen levels at the surface, and tropholytic activity in the bottom, which reduce oxygen levels. In Mettur, the DO curve in surface water paralleled the primary production curve indicating that photosynthesis was the major contributor to oxygen in the water (Sreenivasan 1968). Tirumoorthy presents a peculiar case because the oxygen curve is mostly orthograde and primary production is fairly high.

Carbon Dioxide System and pH

Free CO_2 was present even in the surface waters of soft- and medium-hard-water reservoirs, but was absent in hard-water lakes like Sathanur and Krishnagiri. Even at the bottom (at 24 m), free CO_2 was absent in Sathanur and Krishnagiri. Phenolphthalein alkalinity ranged from 3.75 to 40.0 mg/L in the surface water of Sathanur. The corresponding figure for Krishnagiri was 8.0 to 50.0 mg/L. The maximum vertical differences in pH were 0.8 and 0.9, respectively, for Sathanur and Krishnagiri. These differences are small when compared with other reservoirs because of the buffering effect of the high bicarbonate content. Changes in pH are considered to be an index of productivity (Verduin 1975). The vertical difference in methyl-orange alkalinity (MOA) (bicarbonates) between the surface and the bottom in Mettur, Bhavanisagar, Sandynulla, Sathanur, Krishnagiri, and Uppar indicate utilization in the surface and accretion in the bottom, due to trophogenic and tropholytic activity, respectively.

In the hard waters like Sathanur and Krishnagiri, the carbon dioxide is in the form of CO_3^{2-} and HCO_3^- and the former is less easily abstracted for photosynthesis than the free CO_2–HCO_3 combination. In very soft waters like Pykara, CO_2 is a limiting factor. Carbon dioxide is also a limiting factor in productivity, and metabolic CO_2 is a stimulating factor in productivity (Frah et al. 1966; Kuentzel 1969).

Productivity Parameters and Fish Yields

A study of 13 reservoirs of various sizes and physicochemical features indicated that most of the variables (area, mean depth, drainage basin, total alkalinity, and TDS) do not correlate well with fish yields. The rank order of fish yield did not correspond to the rank order of primary production (P_g), MEI, MOA, or total organic carbon (TOC). In Amaravathy, TOC and P_g were nearer to the rank order of fish production, whereas, in Sathanur, fish yield was nearer to TOC, MEI, and MOA. In Mettur, the rank order of P_g was close to TOC, MOA, and MEI, but not to fish yield. In Bhavanisagar, fish yield was far behind P_g. In the two lowest ranking unproductive reservoirs, there was close correlation or ranking of all the five factors examined (Table 6).

Table 6. Rank order of fish yields and chemical parameters.

Reservoirs	Fish yield	Primary production (P_g)	MEI	MOA (mg/L)	TOC (mg/L)
Palar Porandalar	1	7	8	8	8
Manjalar	2	3	4	4	7
Amaravathy	3	2	11	10	1
Sathanur	4	6	3	2	4
Uppar	5	9	1	1	2
Aliyar	6	8	13	9	5
Tirumoorthy	7	1	9	8	11
Mettur	8	5	6	5	6
Bhavanisagar	9	4	7	7	10
Kirshnagiri	10	10	2	3	9
Vaigai	11	11	5	6	7
Manimuthar	12	13	12	11	3[a]
Pechiparai	13	12	10	12	12

Note: MEI = morphoedaphic index; MOA = methyl-orange alkalinity; and TOC = total organic carbon.

[a] Questionable value.

When transformed into energy units (Table 7), the best conversion of photosynthetic energy to fish was achieved in Palar Porandalar (0.2749%). Initially, this was a tilapia-dominated biotope. However, it has recently changed to carp-dominated (catla, rohu, silver carp, and common carp) water without any reduction in yield. Next best was Manjalar where the conversion of photosynthetic energy to fish was 0.1754%. Here, the catch was predominantly tilapia. Third in rank was Sathanur with a conversion rate of 0.1676% (mainly carps); Amaravathy gave a conversion of 0.1303% (tilapia was 80% of total yield). Uppar, which had the highest MEI, ranked only next to Amaravathy with a conversion rate of 0.1620%. The poorest reservoirs were Manimuthar and Pechiparai. Primary production was low, and its utilization was also poor probably due to poor stocking of suitable species of fish.

A comparison of Vaigai and Uppar shows that conversion in Vaigai was one-eighth that in Uppar. This difference is possibly due to species mix. In Vaigai, the predator *Wallago attu* dominated the catch; in Uppar, it was a carp–tilapia combination. In Krishnagiri, with a comparable primary production, fish yield was less than 50% that in Uppar. This may also be due to faulty management, such as inadequate stocking and lack of optimum effort.

Three reservoirs with identical primary production are Mettur, Bhavanisagar, and Sathanur. In Sathanur, the catch consists mainly of carp (95%); in Mettur and Bhavanisagar, predatory catfish account for over 35% of the catch. In the last few years, tilapia (*Oreochromis mossambicus*) has been appearing in the catches of Bhavanisagar (about 20% of total weight) without improving the total yield.

The dominant role of stocking in reservoir fishery management is illustrated in Aliyar. Stocking of major carp (>10 cm) has yielded better results. The fish catch in 1989–90 was 62 530 kg (96.5 kg/ha per year); it was 25 190 kg (40 kg/ha per year)

Table 7. Energy conversion in select reservoirs in relation to fish yields.

	Mettur	Bhavanisagar	Sathanur	Krishnagiri	Amaravathy	Aliyar
Location (°N)	11°50'	11°30'	12°12'	12°30'	10°30'	10°29'
Total visible						
Average radiation (lx/cm^2 per day)	213	213	212	211	215	215
Radiant energy (J/m^2 per year x 10^5)	32 530	32 530	32 376	32 300	32 836	32 836
Photosynthetic production						
g O_2/m^2 per day	6.20	6.21	6.17	4.27	8.61	4.98
g O_2/m^2 per year	2 263	2 267	2 250	1 555	3 143	1 817
Energy (J x 10^6)	8.147	8.162	8.100	5.610	11.320	6.5412
Conversion of radiant energy to photosynthesis (%)	1.048	1.050	1.047	0.727	1.442	0.834
Fish production						
kg/ha per year	23.6	23.46	113.12	21.51	122.99	28.79
g/m^2 per year	2.36	2.35	11.31	2.15	12.30	2.88
Energy (J/m^2 per year)	11 849	11 799	56 785	10 795	61 756	14 460
Conversion of energy (%)						
Fish/photosynthesis[a]	0.0348	0.0346	0.1676	0.0460	0.1303	0.0538
Fish/light[b]	0.00036	0.00036	0.00175	0.00033	0.00188	0.00044

(continued)

Table 7 concluded.

	Tirumoorthy	Uppar	Vaigai	Manjalar	Manimuthur	Pechiparai	Palar Porandalar
Location (°N)	10°28'	10°01'	10°01'	10°13'	8°39'	8°26'	10°15'
Total visible							
Average radiation (lx/cm^2 per day)	215	215	215	209	216	216	209
Radiant energy (J/m^2 per year x 10^5)	32 836	32 836	32 836	31 916	32 987	32 987	31 916
Photosynthetic production							
g O_2/m^2 per day	10.76	4.44	4.09	6.70	1.80	2.78	5.66
g O_2/m^2 per year	3 927	1 620	1 494	2 446	657	1 015	2 066
Energy (J x 10^6)	14.137	5.832	5.378	8.806	2.365	3.654	7.438
Conversion of radiant energy to photosynthesis (%)	1.801	0.743	0.685	1.154	0.030	0.463	0.975
Fish production							
kg/ha per year	28.47	78.69	8.91	128.67	6.85	4.21	170.35
g/m^2 per year	2.85	7.87	0.89	12.87	0.685	0.42	17.04
Energy (J/m^2 per year)	14 309	39 514	4 473	64 618	3 439	2 109	85 554
Conversion of energy (%)							
Fish/photosynthesis[a]	0.0242	0.1620	0.0199	0.1754	0.0348	0.0138	0.2749
Fish/light[b]	0.00044	0.0012	0.000136	0.00200	0.00010	0.000064	0.00268

[a] Value derived from Fish production (Energy) ÷ Photosynthetic production (Energy).
[b] Value derived from Fish production (Energy) ÷ Total visible (Radiant Energy).

5 years ago. The 5-year average from 1985–86 to 1989–90 was 60.6 kg/ha per year, whereas, for the previous 5 "unmanaged" years it was only 22.24 kg/ha per year. The catch for 1989–90 would bring the conversion to 0.1770%, which could be raised to the level of Palar (0.27%).

Ryder's (1965) equation $Y = KX^a$ does not fit our data, nor does Jenkins' (1967) model $Y = a + bx$. However, a multiple linear equation seems in order.

[2] $Y = a + b_1x_1 + b_2x_2 + ... + b_8x_8$

where Y = yield (kg/ha per year); x_1 = area (ha) at full supply level (FSL); x_2 = drainage basin (ha); $x_3 = Z_m$ (mean depth); x_4 = EC (µmho/cm); x_5 = GPP (P_g) (GPP = gross primary production); x_6 = MOA (ppm); x_7 = Kj-N (ppm); x_8 = TOC; and a and b are constants.

The multiple linear regression on Y is:

[3] $Y = 123.1222 + 0.0192x_1 - 0.0003x_2 + 3.8594x_3 + 0.7586x_4 + 6.44193x_5 - 0.6762x_6 - 2.3493x_7 + 2.6131x_8$

with $R^2 = 0.9683$, which explains 97% of variation, $F = 13.1116$ (7, 3 df); or

[4] $Y = 130.1304 + 0.0194x_1 + 5.6951x_3 + 0.2723x_4 + 7.7171x_5$

with $R^2 = 0.9633$ explaining 96% of variation, $F = 39.4144$ (4, 6 df).

Using the "metabolism concept," productivity measurements were made for a few reservoirs. From changes in CO_2 alkalinity, it was noted that the highest utilization of CO_2 was in Sathanur Reservoir (67 per µmol/L CO_2), followed by Krishnagiri (26 per µmol/L CO_2). Changes in O_2 content were high in Sathanur, Mettur, and Amaravathy, indicating photosynthetic liberation.

Ranta and Lindstrom (1989) "failed to find any relationship between water quality and fish yields." They state that it is practically impossible to predict, reliably, lake-specific fish yields using water-quality parameters as estimators.

According to Adams et al. (1983), empirical relationships based on comparisons of primary production to fish production may be more revealing than MEI. Likewise, Hanson and Leggette (1982) found that the best known index of fish yield, MEI, consistently performed poorly. Prepas (1983) observed that TDS does not seem to be useful in predicting lake productivity. The superior predictive ability of P_g was recognized by McConnell et al. (1977). Natarajan (1979) also recognized that 1% of gross primary production provides a fairly dependable limnological guide to fish productivity. Welcomme (1979) observed that with our present state of knowledge, and using limited regression formulae, we cannot make predictions that are sufficient to fulfill the requirements of year-to-year managerial decision-making. However, energy flow models can serve as a guideline for approximating fish yields in reservoirs.

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Multiple Regression Analysis of Plankton and Water-Quality Relationships as Affected by Sewage Inputs and Cage Aquaculture in a Eutrophic, Tropical Reservoir[1]

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*Predictions of phytoplankton and zooplankton densities using multiple regression analyses of 20 water-quality parameters measured over 15 months in 1986–1989 were accomplished for three stations of the Saguling Reservoir, Indonesia, to compare the effects of: (1) an estimated 50 000 m^3/day of raw sewage (Station 1); (2) a 2 500-t/year cage aquaculture industry for common carp (*Cyprinus carpio*) (Station 9); and (3) control station (Station 8). Significant multiple regression models ($p < 0.05$) relating phytoplankton densities as dependent variables to water-quality parameters explained 94.5% (Station 1), 84.3% (Station 9), and 99.6% (Station 8) of the variance; for zooplankton, regressions explained 94.8%, 72.5%, and 82.1% at the three stations.*

At the sewage-affected station, three significant ($p < 0.05$) negative predictor variables for phytoplankton densities were suspended solids, orthophosphate, and zooplankton. At the cage-aquaculture station, significant positive predictors were dissolved oxygen (DO), biological oxygen demand (BOD), and orthophosphate concentrations; negative predictors were silicate, nitrate, alkalinity, and carbon dioxide. At the control station, significant positive predictors were BOD, total discharge, suspended solids, ammonia, nitrate, temperature, nitrite, and orthophosphate; negative predictors were silicate and conductivity. For zooplankton at the sewage station, significant positive predictors were suspended solids, orthophosphate, and phytoplankton. At the cages, ammonia was the only significant positive predictor, and temperature a significant negative predictor. At the control station, ammonia, BOD, total discharge, temperature, suspended solids, and nitrate were significant positive predictor variables. Multiple regression models developed here support previous studies indicating that cage aquaculture had little influence in altering the direction of change in phytoplankton and zooplankton densities. Cage aquaculture in the Saguling Reservoir cannot be equated with the effects of raw sewage or water-level fluctuations on the aquatic ecosystem.

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[1] ICLARM Contribution 641.

The number of tropical reservoirs in Asia is increasing dramatically. The number of new reservoirs in Asia has increased rapidly as a response to the region's expanding need for electric power and drinking water, and for irrigation water to intensify traditional agroecosystems. As inland areas lose agricultural lands to water projects, development of appropriate management strategies to maximize potential benefits of the new water resources for the displaced population and development of new institutional linkages to rehabilitate the disturbed social–environmental interfaces are urgently needed (IOE-UNPAD and ICLARM 1989; Costa-Pierce 1990; Soemarwoto and Costa-Pierce 1990).

Given these facts and the economics of constructing modern power and water distribution networks, large- and medium-sized reservoirs are now being developed closer to Asian urban centres than ever before. Not only have the problems of resettlement increased because of the increased numbers of people being displaced, but also the pollution of reservoirs is increasing. Urban sewage, previously diluted and carried away in untamed rivers, now accumulates in new reservoirs, causing uncontrolled cultural eutrophication and disease problems.

Cage aquaculture is a promising recent development in Asian reservoirs and lakes (Li and Zweig 1987; Beveridge and Phillips 1988; Swar and Gurung 1988; Costa-Pierce and Hadikusumah 1990). The potential for design and implementation of low-cost and commercial-scale systems in reservoirs is great if institutional and farmer cooperation is planned (Sutandar et al. 1989; Costa-Pierce 1990) and a reservoir's carrying capacity and environmental limits can be predicted (Beveridge 1984). To date, however, guidelines to assist in managing and planning for implementation of profitable aquaculture and fisheries in Asian reservoirs are little known (IOE-UNPAD and ICLARM 1990).

One common concern of planners, dam engineers, and electric-company administrators about the development of cage aquaculture is its environmental effect, and the negative effect upon dam or turbine operations. In addition, pollution of reservoirs is a universal concern. Few long-term monitoring efforts to measure and compare the effects of cage or sewage pollution have been completed in tropical reservoirs. Experiences from the temperate zone show that an alarming quantity of waste is produced by cage aquaculture (Merican and Phillips 1985; Folke and Kautsky 1989). These wastes are thought to be comparable to sewage in their nutrient effect on plankton populations and accelerated, or cultural, eutrophication of water bodies.

A World Bank project by ICLARM and the Institute of Ecology, Padjadjaran University (IOE-UNPAD) from 1986 to 1989 collected large data sets on water quality and on cage culture for environments and systems in the Saguling Reservoir, West Java, Indonesia (Costa-Pierce and Hadikusumah 1990; Soemarwoto et al. 1990). In this paper, I use multiple regression analysis methods to analyze data from three diverse stations to construct empirical models to predict and compare the effects of water quality on the population dynamics of phytoplankton and zooplankton, and to address the comparative effects of commercial cage aquaculture and sewage pollution on the Saguling reservoir environment.

Materials and Methods

All water-quality parameters, analytical methods, and the complete water-quality data base for the analyses done here are detailed in Soemarwoto et al. (1990: appendix 1).

Three stations were chosen for comparison. The sewage-affected station (Station 1) was located at the mouth of the Citarum River as it empties into the northeast sector of Saguling. The Citarum River receives an estimated 50 000 m^3/day of raw sewage from the Bandung–Padalarang–Cimahi urban complex just 20–40 km upstream. Station 9 was located at the geographic centre of the cage-aquaculture industry in the southern region of the reservoir. The cages produce about 2 500 t/year of common carp (*Cyprinus carpio*). Feeding, management practices, and economics of the cage industry have been detailed elsewhere (Costa-Pierce et al. 1988, 1989; Soemarwoto and Costa-Pierce 1990; Sutandar et al. 1990). All water quality parameters at the cage station were measured at a site located between the cage rafts in the most densely congested area. A control station (Station 8) was also established.

From 1986 to 1989, an extensive water-quality monitoring program was conducted (Soemarwoto et al. 1990). For the multiple regressions done here, a complete data set for 20 parameters (18 of water quality plus phytoplankton and zooplankton densities) for three stations was assembled for 15 months (1986 — March, May, and September; 1987 — January, July, September, October, and November; 1988 — January, February, April, June, July, August, and September).

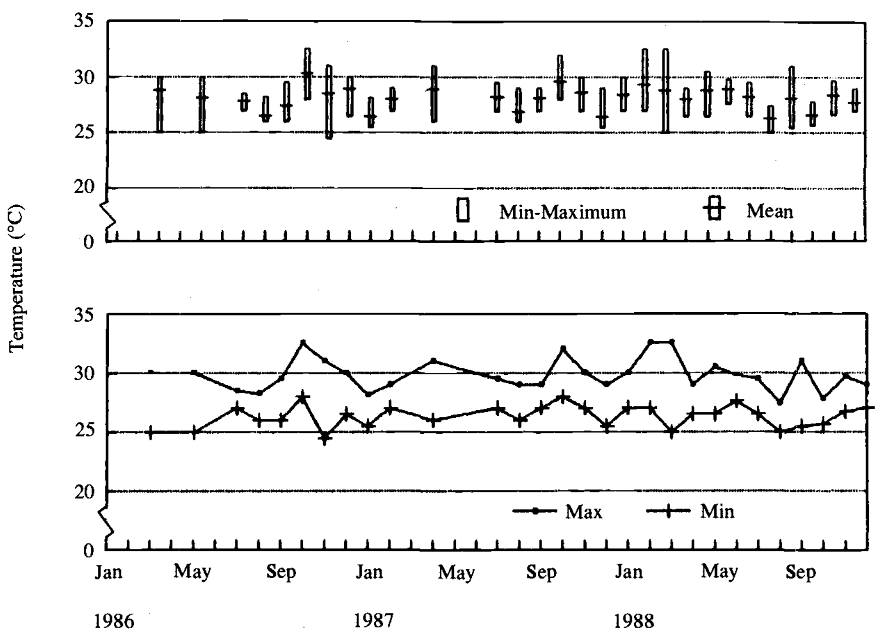

Fig. 1. Water temperatures in the Saguling Reservoir at 20-cm water depth from 1986 to 1988. In the top figure, means, minimums, and maximums are shown; in the bottom figure, only minimums and maximums are shown.

These months were chosen so that a complete data set for all 20 parameters was available. A two-way analysis of variance (ANOVA) indicated that water temperature (Fig. 1) did not exhibit any seasonal or locational differences between stations ($p > 0.01$); therefore, season was not included as a predictor variable in the analysis.

Multiple regression analyses were run to find significant models that related phytoplankton and zooplankton densities (numbers per L) as dependent variables to 18 water quality parameters as independent (or predictor) variables (19 total inputs). Analyses were done using Microstat software (Ecosoft Inc.) on an IBM-compatible personal computer.

A full correlation matrix was separately constructed for all 20 variables at each of the three stations to determine the extent of multicollinearity (Dillon and Goldstein 1984; Hopkins et al. 1989). Variables exhibiting significant correlation at the 99% level were systematically eliminated from the multiple regressions. Eliminations were done according to well-known principles of aquatic chemistry, or were done to emphasize the use of variables easy to measure or more relevant to future water-quality monitoring programs. For example, if significant correlations were found between pH, alkalinity, and carbon dioxide, three models were individually run with each of these variables singularly. The variable producing the largest partial R^2 chosen for the final model. Residuals were calculated to determine the extent of autocorrelation between the included predictor variables using a Durbin–Watson test (Dillon and Goldstein 1984).

Full model multiple-regression analyses were accomplished on the data set from each of the three stations to find the best fit to the data. The best fit was taken as the highest level of significance and adjusted multiple coefficient of determination (R^2) for all possible combinations and number of predictor variables that were found not to be affected by multicollinearity. Adjusted R^2 values were used to compare models for the three stations, because models had different numbers of predictor variables (from 9 to 12). Because the coefficient of determination (R^2) can be artificially increased by simply increasing the number of predictor variables, adjusted R^2 values were used to compare models to adjust for this (Dillon and Goldstein 1984: 222).

Significance levels of the three overall regression models and individual predictor variables explaining the variances observed in phytoplankton and zooplankton densities were compared and contrasted for the three stations.

Results

A number of predictor variables (water-quality parameters) showed a significant amount of multicollinearity (Table 1). As expected, reservoir water-flow characteristics were significantly related. Water inflow into Saguling at Nanjung (Citarum River station), inflow at the Saguling dam site, and total discharge were all correlated ($r = 0.882$–0.987; $p < 0.01$).

At the sewage-affected station (Station 1), reservoir water-flow parameters were positively correlated: input at dam with silicate and ammonia, and input at Nanjung with silicate; and negatively correlated: input at Nanjung with ammonia, and total discharge with ammonia. Significant positive correlations between water-quality

Table 1. Significant ($p < 0.01$) correlations among 20 water quality and plankton variables and correlation coefficients (r) at three stations in the Saguling Reservoir (n = 15).

Variables	r
Station 1 (sewage)	
Alkalinity and carbon dioxide	0.864
Inflow station 1 and ammonia	-0.746
Total discharge and ammonia	-0.743
Inflow dam and silicate	0.716
Suspended solids and nitrate	0.667
Inflow station 1 and silicate	0.666
Inflow dam and ammonia	0.664
Station 9 (cages)	
Nitrite and ammonia	0.80
Secchi disk and water level	0.78
Zooplankton and nitrite	0.74
Zooplankton and ammonia	0.700
Station 8 (control)	
Phytoplankton and zooplankton	0.83
Water level and secchi disk	0.81
Orthophosphate and pH	-0.71
Temperature and alkalinity	-0.65
Reservoir flow parameters	
Inflow station 1 and inflow dam	0.99
Inflow station 1 and total discharge	0.89
Inflow dam and total discharge	0.88

parameters at Station 1 occurred between alkalinity with carbon dioxide, and nitrate with suspended solids.

At the cage station (Station 9) and control station (Station 8), water levels were correlated to Secchi disk visibilities (Table 1). No other reservoir flow characteristics were correlated to water-quality parameters. Zooplankton densities were correlated to nitrite and ammonia concentrations, and nitrite correlated with ammonia at the cage station. At the control station, temperature and alkalinity, orthophosphate and pH, and phytoplankton and zooplankton densities were significantly correlated.

Durbin–Watson tests for autocorrelation showed that, for the zooplankton multiple-regression model at Station 9 (cages), no significant serial correlation existed ($p > 0.05$). For all other models, Durbin–Watson decision rules (Dillon and Goldstein 1984) indicated that the test was inconclusive.

Multiple regressions for phytoplankton densities for the three stations showed the lowest p-values in tests of significance at the control station (Station 8) (adj. $R^2 = p < 0.01$), followed by the sewage-affected site (Station 1) (adj. $R^2 = 0.9450$; $p < 0.05$) and the cage site (Station 9) (adj. $R^2 = 0.8433$; $p < 0.05$) (Table 2). Three significant predictor variables accounted for the fit to the data at the sewage-

Table 2. Multiple regression models for phytoplankton densities with reservoir flow characteristics and water quality parameters as independent variables (n = 15).

	Station 1 (sewage)		Station 9 (cages)		Station 8 (control)	
Independent variables	b	SE	b	SE	b	SE
Water level	226.18	75.45	-1 074.38	634.14	—	—
Total discharge	—	—	—	—	170.06	8.92**
Input at dam	—	—	—	—	—	—
Input at station 1	—	—	—	—	—	—
Temperature	-916.78	454.48	9 230.47	3 889.94	3 063.59	314.35
Secchi disk	—	—	—	—	—	—
Suspended solids	-15.09	2.09**	—	—	53.49	3.78**
Conductivity	-5.89	3.17	—	—	-68.27	6.80**
pH	-4 328.30	1 911.34	—	—	—	—
Carbon dioxide	—	—	-4 946.17	1 422.77*	-429.35	127.23
Alkalinity	-47.26	21.67	-2 564.22	524.00**	-33.15	28.11
Dissolved oxygen	—	—	23 671.82	3 219.91***	—	—
Ammonia	-7.28	8.8	—	—	130.76	13.09**
Nitrite	5.90	5.21	—	—	-50.79	11.80*
Nitrate	—	—	-229.74	51.28**	31.02	1.14**
Orthophosphate	-71.37	10.28**	326.74	87.46*	56.79	6.142*
Silicate	-16.00	46.21	-7 085.57	910.82***	-573.23	29.42**
BOD	—	—	9 769.87	1 728.34**	1 478.27	72.28**
Zooplankton	82.94	6.63**	—	—	—	—
Constant	-73 895.696		492 172.225		-112 905.725	
Adjusted r^2	0.9450		0.8433		0.9958	
F-value	22.855		9.371		277.490	
Probability	0.0128*		0.0120*		0.00360**	

Note: Significance levels of independent variables are indicated by asterisks (*** = $p \leq 0.001$, ** = $p \leq 0.01$; * = $p \leq 0.05$); SE = standard error; BOD = biological oxygen demand.

affected station; seven significant predictor variables accounted for the fit to the data at the cage station; and 10 significant predictor variables accounted for the close fit of the equation to the control data (Table 3).

Multiple regressions predicting zooplankton densities showed the lowest p-values in tests of significance at the sewage-affected (Station 1) (adj. $R^2 = 0.9482$; $p < 0.05$), followed by the control (adj. $R^2 = 0.8207$; $p < 0.05$) and the cage station (adj. $R^2 = 0.7249$; $p < 0.05$) (Table 4). Three significant predictor variables accounted for the regression at the sewage-affected station, six at the control, and two at the cages (Table 5).

Discussion

Results demonstrate that all empirical regression models significantly explained the large majority of variances in phytoplankton and zooplankton densities on the basis of dynamic changes in water-quality parameters measured at all three stations during the 15-month period. The fit to the data explaining variances in phytoplankton densities at the control station was particularly noteworthy ($R^2 = 0.9958$) and highly significant ($p = 0.0036$) (Table 2).

Multiple-regression analysis has been successfully used to explain seasonal distribution patterns in algal species compositions with limnological characteristics (Peterson and Stevenson 1989; Siver and Hamer 1989) and to explain variations in plankton production (Goldman et al. 1968; Platt et al. 1973). These studies were done in the temperate zone, however, where seasonal temperature fluctuations are important predictor variables. The Saguling Reservoir is close to the equator at 6° S latitude, and the region is without strong seasonalities (Fig. 1). Elimination of the seasonality factor allowed these models to focus more specifically upon water quality and plankton interactions.

Table 3. Significant predictor variables for phytoplankton densities at three stations (n = 15).

Variable	Station 1 (sewage)		Station 9 (cages)		Station 8 (control)	
	Positive	Negative	Positive	Negative	Positive	Negative
Alkalinity				**		
Ammonia					**	
BOD			**		**	
Carbon dioxide				*		
Conductivity						*
DO			***			
Nitrate				**	**	
Nitrite					*	
Orthophosphate		**	*		*	
Silicate				***		**
Suspended solids		**			**	
Temperature					*	
Total discharge					**	
Zooplankton		**				

Note: Significance levels are: *, $p < 0.05$; **, $p < 0.01$; and ***, $p < 0.001$; BOD = biological oxygen demand; DO = dissolved oxygen.

Table 4. Multiple regression models for zooplankton densities with reservoir flow characteristics and water quality parameters as independent variables (n = 15).

Independent variables	Station 1 (sewage)		Station 9 (cages)		Station 8 (control)	
	b	SE	b	SE	b	SE
Water level	-2.70	1.14	—	—	10.82	3.08*
Total discharge	—	—	—	—	—	—
Input at dam	—	—	—	—	—	—
Input at station 1	—	—	-3.07	1.04*	—	—
Temperature	11.60	7.01	—	—	346.53	91.72*
Secchi disk	—	—	—	—	—	—
Suspended solids	0.18	0.03*	-1.84	1.05	3.36	0.88*
Conductivity	0.78	0.05	—	—	-2.21	1.64
pH	51.21	27.36	63.27	134.79	—	—
Carbon dioxide	—	—	17.65	32.53	-68.33	28.90
Alkalinity	0.65	0.47	-12.22	7.16	—	—
Dissolved oxygen	1.73	7.23	—	—	—	—
Ammonia	0.076	0.143	4.61	1.03**	16.63	3.81**
Nitrite	-0.07	0.08	—	—	—	—
Nitrate	—	—	0.49	0.45	1.73	0.46*
Orthophosphate	0.885	0.160*	2.51	1.56	—	—
Silicate	0.73	0.714	—	—	-19.42	9.30
BOD	—	—	—	—	131.95	20.23**
Phytoplankton	0.011	0.002*	0.005	0.002	—	—
Constant	854.31		170.91		-12 464.07	
Adjusted r^2	0.9482		0.7249		0.8207	
F-value	22.349		5.099		8.120	
Probability	0.0436*		0.0436*		0.0164*	

Note: Significance levels of independent variables are indicated by asterisks (*** = $p \leq 0.001$, ** = $p \leq 0.01$; * = $p \leq 0.05$); SE = standard error; BOD = biological oxygen demand.

Table 5. Significant predictor variables for zooplankton densities at three stations (n = 15).

Variable	Station 1 (sewage)		Station 9 (cages)		Station 8 (control)	
	Positive	Negative	Positive	Negative	Positive	Negative
Ammonia			***		**	
BOD					**	
Nitrate					*	
Orthophosphate	*					
Phytoplankton	*					
Suspended solids	*				*	
Temperature				*	*	
Total discharge					*	

Note: Significance levels are: *, $p < 0.05$; **, $p < 0.01$; and ***, $p < 0.001$; BOD = biological oxygen demand.

The number of significant predictor variables explaining variances for both phytoplankton and zooplankton densities was greater at the control station than the sewage- and cage-affected stations. I interpret this to mean that a simplification of the nutrient pathways and the aquatic ecosystem occurred in these latter stations; nutrients were less limiting in comparison with the control station.

The effect of water-quality parameters on phytoplankton densities at the sewage-affected station was completely inverse from the effect on zooplankton densities (Tables 3 and 5). Sewage has a large quantity of suspended solids, which decrease light penetration and negatively affect phytoplankton densities. Evidently, high concentrations of suspended solids had the opposite effect on zooplankton densities.

Predictors affecting the dynamics of phytoplankton densities at the sewage-affected station were entirely different from factors causing changes noted at the other stations. For zooplankton, only the concentrations of suspended solids had a similar positive effect on densities similar to those at the control station.

The cage station and sewage-affected station showed different effects of water-quality predictor variables. At the cage site, the models predicted that, when concentrations of nutrients (silicate, nitrate, and alkalinity) were low, phytoplankton populations were high; an inverse effect was noted at the control station. This is either because nutrient levels at the control station were lower (Soemarwoto et al. 1990) or phytoplankton densities were limited by nutrients, in contrast to the cage station. However, the cage station shared four of its seven predictor variables for phytoplankton densities with the control station.

These multiple-regression analyses of water-quality parameters indicate that the water-quality dynamics affecting phytoplankton and zooplankton densities at the cage culture and control stations were more similar than those at the sewage-affected station, where water-quality dynamics were greatly simplified. The implication is that effects of water quality on plankton densities were station-specific and that the dynamics of change in the plankton systems at the cage station, although altered, were entirely different from those at the sewage-affected station. These hypotheses are in agreement with earlier experimental work of Costa-Pierce and Roem (1990) who measured nutrient and solids output from cage aquaculture of common carp (*Cyprinus carpio*) in the Saguling reservoir. That study found that cage wastes contributed few nutrients to the reservoirs in comparison with other endogenous and exogenous inputs such as nutrients from decomposition of flooded organic matter at the reservoir flooding stage, or from sewage inputs.

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Utilization of Aquatic Plants in Songkhla Lake, Thailand

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Songkhla Lake is the largest natural lake in Thailand (98 600 ha). The lake connects to the gulf of Thailand and the salinity varies from 0 to 30‰ depending on the season and on the distance from the sea. Thale Noi is a freshwater part of the lake with a surface area of 2 500 ha. It is slightly acidic, has 19 species of aquatic plants, and a biomass ranging from 6 to 21 kg/m², depending on season.

A 4-year study was undertaken to attempt to use this weed as a source of fish feed and to find an appropriate weed-management technique. Four popular herbivorous fish species, Oreochromis niloticus, Labeo rohita, Ctenopharyngodon idella, *and* Puntius gonionotus, *were tested under the reservoir conditions for 1 year. Nile tilapia (*O. niloticus*) and Indian carp (*L. rohita*) performed best.*

From fish culture and nutrition studies, O. niloticus *was found to be the most suitable species for culture. Mono- and polyculture and integrated culture with pigs and chickens with single and multiharvesting were tested with* O. niloticus *maintained on a weed-based feed. Aquatic-weed pellets were also used as an animal feed for omnivorous fish, pigs, and chickens.*

Songkhla Lake is the largest natural lake in Thailand (98 600 ha). The lake is connected to the Gulf of Thailand, and is divided into three parts: the uppermost, freshwater, portion that includes 70% of the lake surface; the middle, brackish-water, area that includes 5% of the lake surface; and the lowest part of the lake that is seawater (Bhommanonta, P., personal communication 1989; Davy 1981).

Thale Noi is a freshwater lagoon (2 500 ha) connected to the uppermost part of Lake Songkhla. Thale Noi, and the uppermost part of Lake Songkhla, contain a large number of aquatic weeds (*Ceratophyllum demersum*, *Hydrilla verticillata*, *Najas graminea*, *Utricularia minor*, and *Blyxa japonica*, see Fig. 1) that bloom year-round. Davy (1981) estimated that 140 625 t of aquatic weeds are produced annually. In 1979, 1 800 t of aquatic weeds were harvested from the upper part of the lake for animal feed (Fisheries Office, Phattalung Province, personal communication 1979; Tansakul et al. 1987).

More than 200 fishermen work in Thale Noi, mostly with gill nets and encircling seines (John Taylor and Sons et al. 1985). Thale Noi is heavily fished and yields 500–600 t/year of freshwater fish worth about 8 million THB (20 THB =

Fig. 1. Thale Noi is densely covered by aquatic weeds.

1 USD) or 36.0% of the annual income of Thale Noi community (ISTT 1982). Fisheries continue to be an important source of income for the villagers; however, fish yields have decreased over the years and are not enough to support the people who are engaged in fisheries (Rittibhonbhun et al. 1984). Aquaculture in Thale Noi could provide a new source of food protein and income for the villagers. With particular regard to Thale Noi, the culture of herbivorous fish may offer the most potential to utilize the abundant aquatic macrophytes, which produce an annual biomass of 146 kg/m^2 (Purintavaragul and Lheknim 1984). Several species of fish feed on aquatic macrophytes — grass carp (*Ctenopharyngodon idella*), *Puntius gonionotus*, *Osphronemus gorami*, *Tilapia* spp, *Trichogaster pectoralis*, and *Labeo rohita* (Edwards 1980).

Herbivorous fish are very beneficial both for local consumption and for the control of aquatic macrophytes. There are several constraints to aquaculture in the area, however, such as climate, water quality, and appropriate sites (Chiayvareesajja et al. 1988).

Results and Discussion

Water Quality

In 1982/83, water-quality parameters and plankton biomass were checked (Table 1; Fig. 2). There were no significant differences in water depth, water temperature, alkalinity, and nitrate level among the stations, but there were significant differences in other parameters. The average water depth of Thale Noi ranged from 104 cm (station 3) to 126 cm (station 4). The pH ranged from 5.6 (station 3) to 6.9 (station 4), with the lowest pH of 3 recorded at station 3 during November and December 1982. Annual dissolved oxygen ranged from 3.9 ppm

Table 1. Water quality and plankton biomass at five stations in Thale Noi Lake (mean ± standard error)[a].

Parameter	Stations 1	2	3	4	5
Depth (cm)	107.2 ± 8.7^{ns}	125.0 ± 8.3^{ns}	103.9 ± 11.0^{ns}	126.5 ± 8.4^{ns}	112.7 ± 9.5^{ns}
Temperature (°C)	28.9 ± 0.4^{ns}	29.5 ± 0.4^{ns}	29.1 ± 0.5^{ns}	29.3 ± 0.5^{ns}	30.0 ± 0.4^{ns}
Disolved oxygen (ppm)	5.2 ± 0.6^{A}	6.2 ± 0.6^{AB}	4.5 ± 0.6^{AC}	6.4 ± 0.6^{AB}	3.9 ± 0.6^{AC}
Alkalinity	16.0 ± 3.5^{ns}	19.5 ± 3.7^{ns}	16.4 ± 2.8^{ns}	14.9 ± 3.2^{ns}	16.7 ± 2.1^{ns}
pH	6.6 ± 0.3^{A}	6.9 ± 0.3^{AB}	5.6 ± 0.5^{ns}	6.1 ± 0.4^{AB}	6.1 ± 0.3^{ABC}
Nitrate (ppm)	0.0 ± 0.0^{ns}	0.0 ± 0.0^{ns}	0.0 ± 0.0^{ns}	0.0 ± 0.0^{ns}	0.0 ± 0.0^{ns}
Nitrite (ppm)	0.0 ± 0.0^{A}	0.0 ± 0.0^{B}	0.0 ± 0.0^{AB}	0.0 ± 0.0^{B}	0.0 ± 0.0^{B}
Phosphate (ppm)	0.0 ± 0.0^{A}	0.0 ± 0.0^{B}	0.0 ± 0.0^{B}	0.0 ± 0.0^{B}	0.0 ± 0.0^{B}
Sulphate (ppm)	9.1 ± 2.3^{A}	14.1 ± 4.0^{A}	69.0 ± 17.4^{B}	21.9 ± 4.1^{A}	13.3 ± 2.7^{A}
Phytoplankton biomass (mg/m^3)[b]	940.5 ± 268.4^{A}	440.1 ± 80.6^{B}	196.8 ± 57.0^{B}	318.0 ± 54.7^{B}	271.4 ± 52.0^{B}
Zooplankton (no./10 mL)[b]	$1\,083.7 \pm 302.1^{A}$	$6\,251.8 \pm 1\,244.0^{B}$	$1\,751.2 \pm 504.3^{A}$	$4\,817.1 \pm 1\,128.5^{B}$	987.7 ± 460.0^{A}

Source: Chiayvareesajja et al. 1988.

[a] Mean values with a common superscript were not significantly different at $p < 0.05$.

[b] Data collected April 1982 to February 1983. All other data collected February 1982 to February 1983.

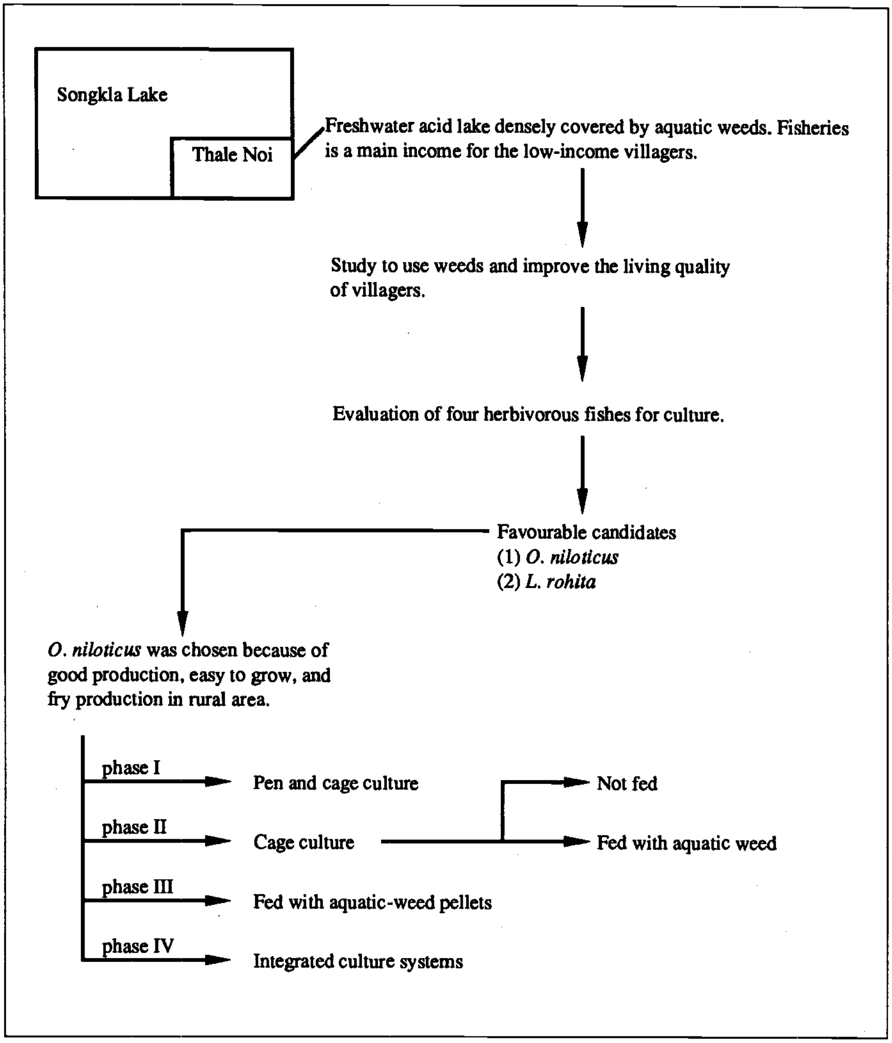

Fig. 2. Schematic representation of the steps undertaken in this study.

(station 5) to 6.4 ppm (station 4), with the highest concentration of 10 ppm recorded at station 4 in February 1982 and the lowest concentration of 1 ppm recorded at station 3 in September 1982. The levels of nitrate ranged from 0.024 ppm (station 4) to 0.036 ppm (station 1). The average levels of phosphate ranged from 0.005 ppm (station 4) to 0.022 ppm (station 1).

Phytoplankton Biomass

The highest level of annual phytoplankton biomass was 940.5 mg/m^3 at station 1 and the lowest level was 196.8 mg/m^3 at station 3. There were no significant differences in phytoplankton biomass among stations 2, 3, 4, and 5. Moreover, there were no significant differences in the correlation coefficients between phytoplankton biomass and nitrate, phosphate, and pH (Chiayvareesajja et al. 1988).

Zooplankton

Six groups of zooplankton were recorded (Ciliata, Rotifera, Copepoda, Nauplius larva and copepodite stage, Cladocera, and Ostracoda). Rotifers were the most abundant at all stations throughout the year, and nauplii and copepodite stages were next. The highest zooplankton densities were recorded at station 2 (Chiayvareesajja et al. 1988).

Fish Culture

Thale Noi is very productive. Unfortunately the pH is low (Tansakul 1985). Herbivorous fish culture for aquatic weed control was tested in the area between 1981 and 1984. Figure 2 shows the various steps that were adopted in this study.

After a preliminary test period of 12 months, *Labeo rohita* and *Oreochromis niloticus* proved to be better candidates than *Ctenopharyngodon idella* and *Puntius gonionotus* for rearing in Thale Noi. Grass carp, which is a promising species for controlling aquatic weeds (Bhatia 1970; Edwards 1980; Fowler 1985), grew very well and reached a size of 1–2 kg in Thale Noi fish pens. However, high mortality, cost, and unavailability of fry did not favour further studies. *Puntius gonionotus* was eliminated because of its slow growth rate and low survival rate. *Labeo rohita* and *O. niloticus* showed better survival rates and better fish production than grass carp and *P. gonionotus*.

Labeo rohita and *O. niloticus* lived and grew well in the preliminary experiments, where the fish were not fed and had to depend solely on the weeds in the bamboo pens.

Production of *O. niloticus* in Thale Noi pens was high with a high stocking density (SD) when the fish were fed only aquatic plants. The higher SD of 30 fish/m^2 was more productive than the lower SD (3 fish/m^2), which is the standard recommended by the Department of Fisheries for tilapia culture in earthen ponds. However, the productivity of 1.08 kg/m^2 was very much lower than that of tilapia cultured in cages in Côte d'Ivoire (Coche 1982).

Productivity of *L. rohita* in the pens was similar to that of *O. niloticus* (0.5–1.02 kg/m^2) in 14 months, and the higher SD (10 fish/m^2) was more productive than the lower SDs (3 and 1 fish/m^2). *Labeo rohita* may also be useful for weed control; however, *O. niloticus* was selected for feed-trial studies after consideration of other socioeconomic factors.

Oreochromis niloticus that were not given food and *O. niloticus* that were fed with 5% body weight of fresh *C. demersum* gave similar results (Tansakul et al. 1987). This suggests that *O. niloticus* can grow well on microplanktonic algae and benthic microorganisms, as was found by Moriarty and Moriarty (1973) in Lake George, Uganda. When *O. niloticus* were fed with chicken pellets, productivity figures were three times higher than when they were fed with fresh *C. demersum* or received no additional feeding. However, the very high food-conversion rate of 15.10 would greatly increase production costs. When the overall production costs are taken into consideration, the feeding of *O. niloticus* on chicken pellets may not be suitable for rural subsistence farms such as those in Thale Noi.

The suitability of the aquatic weeds *C. demersum*, *Eleocharis ochrostachys*, and *Eichhornia crassipes*, the three most abundant species in Thale Noi, for feeding tilapia (*O. niloticus*) was also evaluated. The weeds were used to prepare fish pellets with 16, 25, and 35% crude protein content (40, 30, and 20% dry weeds) (Tables 2 and 3). The control pellet was a chicken pellet (Centaco Co., 16.81% crude protein).

After 11 weeks, fish showed 86–90% survival. During the 1st and 2nd weeks, treatments showed no difference in growth. However, during weeks 3–11, fish fed with pellets of higher protein level grew better (Table 4). Fish fed with different plants at the same protein level showed no statistical difference in growth (Table 4).

Fish fed with 35% crude protein grew best, probably indicating that *O. niloticus* requires a minimum protein level of more than 25% (De Silva and Perera 1985; Klinnavee et al. 1990). Fingerling *O. niloticus* 6.5–35 g in size required optimum protein of 30–35% (Jauncey 1982; De Silva and Perera 1985).

The pellets with low percentages of crude protein showed higher food-conversion rates (Table 3). High fibre in fish feed causes low feed digestion and low absorption (Appler and Jauncey 1983). Fish fed low (16%) crude protein levels may receive insufficient vitamins and minerals and have higher feed-conversion rates (FCR) (Jauncey and Ross 1982; Sritasit et al. 1982).

Another study was conducted with a simple dietary formula containing dry weeds, rice bran, and fish meal in the ratios 4:3:1 and 4:2:2. The most appropriate feed was the 4:3:1 pellet, which gave the cheapest feed (3.15 THB/kg) and the highest profit (13.02 THB/cage, excluding cost of cage and labour). However, further improvement of the pellet is desirable because it resulted in poorer growth than commercial fish pellets. On the basis of crude protein, lipid, and fibre content, the nutritive value of the 4:3:1 feed meets the requirements of tilapia (Jauncey and Ross 1982). However, rates of nutrient assimilation are unknown because there are no data on the digestibility of each component. The crude protein and lipid content of the two types of aquatic-weed pellets were markedly higher than that of the commercial pellet, but the gross energy content of both aquatic-weed pellets was lower. Food energy is an important factor affecting fish growth because the amount of protein assimilated depends on the amount associated with assimilable food energy (Bowen 1982). An increase in food-energy level is necessary to improve the aquatic-weed pellet. Such an improvement is economically feasible because the cost of the aquatic-weed pellet is much lower than commercial fish pellets (Chayvareesajja et al. 1990).

Integrated Systems

An integrated culture system using local strains of chickens fed with aquatic-weed pellets was evaluated. Another study evaluated the use of aquatic-weed pellets as feed for rearing Nile tilapia and pigs. Furthermore, to maximize limited resources, tilapia production using pig manure was studied.

The nutritive value of the formulated feed was much higher than pig feces. The crude protein and lipid content of the formulated feed and the pig feces were (on a

Table 2. Composition of experimental diets fed to *O. niloticus*.

Composition (%)	Dietary treatments 2	3	4	5	6	7	8	9	10
Fish meal	14.6	34.1	58.0	18.5	36.1	59.1	22.3	39.8	62.8
Ceratophyllum demersum	40.0	30.0	20.0	—	—	—	—	—	—
Eichhornia crassipes	—	—	—	40.0	30.0	20.0	—	—	—
Eleocharis ochrostachy	—	—	—	—	—	—	40.0	30.0	20.0
Rice bran	40.2	31.1	17.0	34.3	26.8	13.9	29.3	22.9	11.5
Cassava starch	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	—
Beef wax	4.2	3.8	4.0	6.2	5.2	5.1	7.5	6.4	5.7

Source: Klinnavee et al. (1990).

Table 3. Proximate analyses (mean ± SE) of the experimental diets (% dry weight).

Dietary treatments	Moisture content (%)	Crude protein (%)	Crude fat (%)	Ash (%)	Crude fibre (%)	N-free extract (%)	Gross energy (kJ/100 g)
1	10.2	16.8 ± 0.3	3.2 ± 0.1	6.7 ± 0.0	4.1 ± 0.3	59.0	1 521.7
2	5.8	17.1 ± 0.1	13.9 ± 0.6	17.4 ± 0.1	8.2 ± 0.0	37.8	1 583.6
3	6.2	24.5 ± 0.1	11.8 ± 0.1	19.5 ± 0.2	6.5 ± 0.1	31.6	1 553.1
4	4.4	34.4	10.6 ± 0.1	23.5 ± 0.3	4.2 ± 0.0	22.9	1 588.7
5	7.7	17.1 ± 0.0	14.0 ± 0.4	14.5 ± 0.2	11.7 ± 0.0	35.1	1 528.4
6	6.7	24.4 ± 0.1	12.4 ± 0.0	17.8 ± 0.2	8.5 ± 0.2	30.2	1 552.3
7	7.3	34.6 ± 0.2	10.7 ± 0.1	23.1 ± 0.4	5.8 ± 0.7	18.5	1 519.6
8	5.8	17.0 ± 0.1	13.8 ± 0.1	13.5 ± 0.2	12.9 ± 0.8	37.0	1 550.6
9	8.3	24.4 ± 0.2	11.9 ± 0.6	16.4 ± 0.3	10.5 ± 0.0	28.4	1 503.7
10	6.7	34.8 ± 0.1	11.0 ± 0.7	23.7 ± 0.4	6.7 ± 0.3	16.7	1 520.5

Source: Klinnavee et al. (1990).

Table 4. Growth, survival, and food conversion rate of *O. niloticus* after 11 weeks of experimental feeding.

Experimental diets (mean ± SE)[a]	Initial weight (g)	Final weight (g)	Mean weight gain (%)	Specific growth rate (%/fish per day)	Mean food conversion rate	Survival (%)
1[b]	7.7 ± 1.6^{A}	26.2 ± 7.0^{BC}	238.4 ± 4.4^{BCD}	1.6 ± 0.0^{BC}	2.6 ± 0.2^{BC}	97.8^{A}
2	7.2 ± 1.5^{A}	16.8 ± 4.7^{A}	132.0 ± 1.8^{A}	1.1 ± 0.0^{A}	3.7 ± 0.1^{A}	100^{A}
3	7.6 ± 1.7^{A}	25.4 ± 8.0^{BC}	232.7 ± 5.9^{BCD}	1.6 ± 0.0^{BC}	2.5 ± 0.2^{BC}	100^{A}
4	7.5 ± 1.9^{A}	27.9 ± 7.6^{CD}	266.1 ± 10.9^{CD}	1.7 ± 0.0^{BC}	2.0 ± 0.4^{CD}	95.6^{A}
5	7.7 ± 1.5^{A}	16.2 ± 3.7^{BC}	117.1 ± 2.2^{A}	1.0 ± 0.0^{A}	4.3 ± 0.3^{A}	98.9^{A}
6	7.9 ± 1.7^{A}	24.5 ± 7.5^{BC}	212.7 ± 36.4^{BC}	1.5 ± 0.2^{B}	2.7 ± 0.3^{B}	97.8^{A}
7	7.7 ± 1.6^{A}	29.2 ± 8.8^{CD}	281.9 ± 3.0^{D}	1.7 ± 0.0^{CD}	2.1 ± 0.3^{CD}	98.9^{A}
8	7.5 ± 1.6^{A}	16.4 ± 5.1^{A}	122.1 ± 16.7^{A}	1.0 ± 0.1^{A}	3.9 ± 0.2^{A}	100^{A}
9	7.4 ± 1.7^{A}	22.0 ± 7.0^{B}	198.6 ± 16.0^{B}	1.5 ± 0.1^{B}	2.7 ± 0.2^{B}	98.9^{A}
10	7.1 ± 1.9^{A}	31.7 ± 11.0^{D}	346.5 ± 43.4^{C}	1.9 ± 0.1^{D}	1.9 ± 0.2^{D}	100^{A}

Source: Klinnavee et al. (1990).
[a] Within a column, values with the same superscripts are not significantly different ($p < 0.01$).
[b] Control.

dry-weight basis) 24.25% and 12.69%; and 14.15% and 5.66%, respectively (Chiayvareesajja et al. 1989).

All pigs grew well on the weed pellet and the percentage weight gain was high (1 074%). The average loadings of pig feces and urine were 6.42 kg/day and 6.24 kg/day, respectively, for three pigs.

Growth performance of tilapia in the two systems was similar. However, although there was no significant difference between tilapia production in the two systems, the production in the integrated system was slightly higher than in the monoculture system (88.0 and 71.5 kg/compartment, respectively, Table 5). The percentage weight gain of tilapia in the monoculture system was much higher than in the integrated system. The FCR of tilapia fed the formulated feed (4.05) was much better than tilapia fed on piggery waste (25.77). The FCR of 7.39 of pigs fed on aquatic-weed pellets was relatively high.

At the final harvest, the number of tilapia in both systems was higher than the number stocked, and the integrated system had twice the number of fish (2 360 and 1 155 fish/compartment, respectively). Furthermore, most tilapia in the integrated system (72.08%) were 10–15 cm in length; whereas, 45.97% in the monoculture system were >15 cm long (Chiayvareesajja et al. 1989). The yield in this study was similar to that of Green et al. (1989).

There were no significant difference in carcass qualities of tilapia reared in monoculture and integrated culture systems, but there were differences in chemical composition (Wongwit et al. 1990).

Tilapia (*O. niloticus*) reared in the three systems (integration of tilapia and chickens, monoculture of tilapia, and integration of tilapia and pigs) were sampled and analyzed for carcass quality after 6 months of rearing. Chickens and pigs in integrated systems and tilapia in monoculture were fed on aquatic-weed (*Ceratophyllum demersum*) pellet. The chemical composition of the chicken manure, aquatic-weed pellets, pig feces, and carcasses of fish in each system were

Table 5. Growth performance of tilapia and pigs (mean ± SE) from 30 May to 22 November 1987.[a]

		Integration	
Item	Tilapia	Tilapia	Pig
Initial number (no./compartment)	640	640	3
Final catch (no./compartment)	1 155 ± 185	2 360 ± 450	3 ± 0
Number in final catch (%)			
5–10 cm class	11.1 ± 1.2	11.9 ± 1.8	
10–15 cm class	42.9 ± 1.3	72.1 ± 1.6	
>15 cm class	46.0 ± 1.2	16.1 ± 2.5	
Average initial weight[b]	4.3 ± 0.2^{A}	5.6 ± 0.1^{B}	5.9 ± 0.2
Average final weight[b]	62.4 ± 1.7^{C}	37.1 ± 0.7^{D}	69.4 ± 0.4
Average % weight gained	$1\ 329.8 \pm 102.7^{E}$	563.8 ± 26.9^{F}	1 074.7 ± 34.3
Total production (kg/unit)	71.5 ± 9.8^{H}	88.0 ± 17.8^{H}	208.3 ± 0.3
Food conversion rate	4.1 ± 0.7	25.7 ± 4.3	7.4 ± 0.3

Source: Chiayvareesajja et al. (1989).
[a] Values in rows with the same superscript were not significantly different ($p < 0.05$).
[b] Units for initial and final weight are g/individual for tilapia and kg/individual for pigs.

analyzed by proximate analysis. Levels of crude lipid and crude fibre of the fish carcasses were lowest (13.50% and 0.53%, respectively) and levels of crude protein and ash were highest (59.54% and 24.64%, respectively) in the integrated tilapia–chicken system.

There were no significant differences in the ratios of dry flesh to dry body weight (FBdR) and dry bone to dry flesh weight (BnFR) between the two integrated systems. The carcasses of the tilapia in monoculture were the best on the basis of the highest value of FBdR (83.23%) and the lowest value of BnFR (20.37%) (Wongwit et al. 1990).

Practical aquaculture training was given to small-holder farmers to allow them to raise tilapia in 5 × 5 m bamboo cages with some subsidies from the project. Unfortunately, due to two monsoon storms and floods in 1987 and 1988, and the low profit from fish culture, farmers stopped their fish raising (unpublished data).

Rearing *O. niloticus* with aquatic weeds is not only a way to control undesirable weeds, it also increases the local stocks of natural fish (Edwards 1980). Furthermore, it may be a way to increase the income of the villagers in the area.

The results of this study suggest that further research into reducing the costs and increasing the quality of aquatic-weed pellets may be appropriate. If these techniques are established, they may be useful in other similar freshwater reservoirs in Thailand and Southeast Asia.

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Detritus Production and Its Utilization by *Oreochromis mossambicus* in Seletar Reservoir

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The level of detritus production was studied in Seletar reservoir, a commercially unfished, tropical, 300-ha freshwater impoundment used strictly for drinking-water storage in Singapore. Its availability and degree of utilization by Oreochromis mossambicus *was also investigated. Detritus production was measured by suspending replicate collectors in the reservoir. The rate of consumption and assimilation efficiency of the detritus produced was evaluated using bomb calorimetry. About 34.7 kg C/ha per day of detritus, consisting mainly of oxidizable materials with only 7% ash, was produced.*

Juvenile and adult O. mossambicus *fed mainly on detritus and only about 50% of the detritus was assimilated. Based on the rate of detritus produced, the observed proportion of juvenile and adult fish, and their detrital comsumption rates, it was estimated that the 300-ha Seletar reservoir could probably support a population much greater than the 15 million tilapia estimated from mark–recapture studies. Other considerations such as availability of detritus, the use of detritus by species other than fish, and the pivotal role of tilapia as a detritivore in the ecosystem are discussed.*

Detritus in this study refers to the aggregate of partially decomposed organic matter of both plants and animals that once lived in the overlying water column, a mixture of algae that has settled to the bottom, as well as bacteria. The dominant and most abundant fish species in Seletar reservoir, a 300-ha freshwater impoundment located near the middle of Singapore island, was the tilapia, *Oreochromis mossambicus*. Tilapias possess suitable morphological and physiological adaptations to utilize detritus (Bowen 1982). Their trophic abilities make them ideally suited to exploit the detrital resources of Seletar reservoir. Because they occupy the base of the food chain, the carrying capacity of the reservoir ecosystem should be high for these organisms.

The purpose of this study was to assess the production capacity of detritus in Seletar reservoir and its carrying capacity for the main detritivore fish species *O. mossambicus*.

Materials and Methods

Food and Feeding Habits of Tilapia in Seletar Reservoir

Food composition, feeding intensity, and the relationship between stomach content volume and size of the tilapia in Seletar were examined.

The stomach contents of fish obtained from the reservoir were examined under the microscope. Food compositions and preferences of juveniles (<15 cm) and adults (>15 cm) were examined.

Feeding intensity was examined by degree of feeding (full, three-quarter full, half full, one-quarter full, and empty), and frequency of occurrence of each food category was recorded in adult (>15 cm) and juvenile fish (<15 cm). The study was conducted between April and October 1975.

The monthly volume of individual stomach contents of fish of various sizes was measured by removing the contents and allowing them to settle overnight. About 10 or more stomachs for each 1-cm size class were measured per month. The monthly mean stomach content volumes were then related to the standard length of the fish.

Metabolic, Consumption, and Assimilation Rates

Metabolic rates of juvenile and adult tilapia were measured using the static method for determining the oxygen consumption rate. The respiratory rate was determined by measuring the oxygen content of the water (which was prevented from coming into contact with air) before and after the experimental animal has been placed in the container for a known period of time. Winkler's method (Hoar and Hickman 1967) was used for oxygen determination.

Detritus comsumption rates of the fish were determined from the time taken, and the volume of detritus required, to fill the stomach. Assimilation rates were measured by the difference between the amount consumed and the amount defecated in a fixed time.

The time for the fish to fill their stomachs was investigated by starving about 16 fish (6.1–9.0 cm standard length) for about 1 week and placing them in 10-L tanks. Two fish were placed in a tank and fed with excess known amounts of dried powdered detritus, which were collected as described below. At intervals of 4 h, two fish from a tank were sacrificed and the stomach contents measured in a 10-mL measuring cylinder. The volume of food in the fish was measured up to 28 h after the start of the experiment.

Assimilation rates of juvenile and adult fish were examined by starving the fish and feeding them for about 20 h at room temperature (28 ± 1°C) with known amounts of dried detritus, produced from collections made in the reservoir — 20 h is the time taken by the fish to fill their stomachs. Five juvenile and five adult fish were studied. After feeding, the fish were transferred to special tanks (wire mesh was placed at the base of the tank to prevent the fish from ingesting feces) where they were allowed to defecate. Excess food left in the first tank was filtered in a millipore filter and dried to constant weight at 70°C. The difference between the amount fed and the amount uneaten provided the measure for consumption rate.

Feces collected in the second tank were also filtered and dried as above. The difference between the amount consumed and the weight of feces provided the measure of amount assimilated by the fish.

Energy values of dried detritus, stomach contents, and feces were determined by bomb calorimetry. Assimilation efficiency (A_e, %) was then calculated by:

[1] $A_e = [(FC_e - F_e)/FC_e] \times 100$

where FC_e = energy of food consumed and F_e = energy of feces.

Detritus Production in Seletar Reservoir

Two sediment collectors, each holding five 1-L sampling bottles and having a total collecting surface area of 23.77 cm^2, were suspended at a depth of 9 m from a floating platform at each sampling station for 1 week (Fig. 1). The 1% light penetration depth was about 6 m at deeper stations (Khoo et al. 1977). The volume of detritus collected was measured in a calibrated sedimentation funnel after overnight sedimentation in the laboratory. Four of the samples per week were filtered through millipore filters (pore size 0.45 µm) and their wet weight was measured after standing in air for 1 h. They were then dried to constant weight at 70°C for 24 h to determine their dry weight. Detritus was collected from July to October 1975 at weekly intervals.

C, H, and N Composition and Calorific Values of Detritus

Two samples of dried powdered detritus were analyzed by the microanalytical laboratory of the Chemistry Department, University of Singapore, for detailed C, H, and N. Energy values of samples of detritus, stomach contents, and feces were also determined.

Population Biology of Tilapia in the Reservoir

Population parameters of tilapia in the reservoir were obtained from Khoo (1983).

The length–frequency distribution (by %) of the tilapia population was determined by a "carcass census" method. The number of dead fish and their respective lengths were monitored along the Sembawang Arm shore of the reservoir for 4 months at weekly intervals from July to October 1975. Assuming that the mortality rates due to environmental factors were similar for all sizes, then the percentage length–frequency of these dead fish would reflect the existing length–frequency composition of the living tilapia population in the reservoir. These data were then used with the average stomach content volume to estimate the total amount of detritus that the existing population of tilapia would require, and to compare this value with the estimated amount of detritus produced in the reservoir.

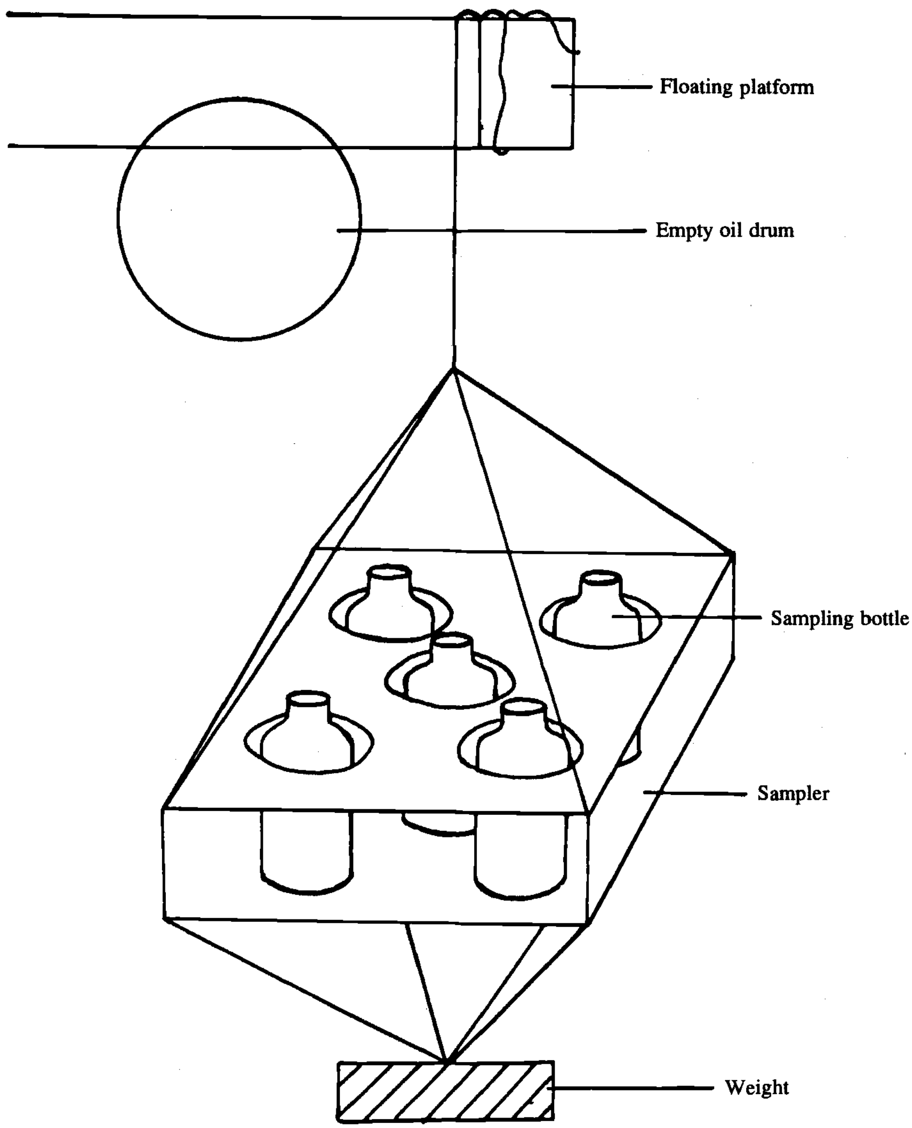

Fig. 1. The detritus sampler.

Results

Food and Feeding Habits of Tilapia in Seletar Reservoir

Food Composition

Only phytoplankton were found in the stomachs of 1-week-old fry. *Ceratium* spp and *Microcystis* spp were the dominant food items. They were also the most abundant and available in the reservoir (Khoo et al. 1977).

The juvenile tilapia fed on both phytoplankton and detritus. Their stomachs contained about 25% detritus and the rest was mainly phytoplankton. The quality of the diet did not vary much from month to month. The main types of phytoplankton eaten were *Ceratium* spp, *Microcystis* spp, *Sphaerocystis* spp, and *Aphanocapsa* spp. Other types include *Melosira* spp, *Chroococcus* spp, and *Oocystis* spp.

The adults were essentially detritivorous. About 75% of their total food volume consisted of detritus and there was not much monthly variation. A small proportion of undecomposed phytoplankton was also observed. The phytoplankton could have settled to the bottom and been eaten by the fish together with the detritus. Almost no copepods or other zooplankton were observed in the stomach contents although they were abundant in the reservoir (Lee 1975). The adults therefore essentially feed demersally, mainly on the bottom detritus.

Feeding Intensity

From April to October, both the adult and juvenile fish in the reservoir showed a high frequency of feeding, except for the adults in October when the water level of the reservoir was low. The monthly feeding intensity is shown in Table 1.

The volume of stomach contents shows an exponential relation to the size of the fish. This indicates that the amount eaten by the fish increases exponentially as it grows (Table 2) and has a higher energy demand for metabolism and growth. The relationship is given by:

[2] $\ln(\text{stomach volume}) = 2.186 \ln(\text{length of fish}) - 5.877$

Table 1. Monthly feeding intensity and frequency in juvenile and adult fish.

Month	Degree of fullness[a]					No. examined
	F	$^3/_4$ F	$^1/_2$ F	$^1/_4$ F	E	
Juvenile						
Apr	43	40	20	14	2	125
May	28	36	39	20	0	123
June	9	13	16	18	0	55
July	15	9	3	5	1	33
Aug	8	15	10	1	0	34
Sep	—	—	—	—	—	—
Oct	2	3	15	7	3	30
Adult						
Apr	6	11	4	13	8	42
May	12	4	2	1	1	20
June	16	5	3	11	4	39
July	14	6	4	3	3	30
Aug	5	1	4	3	1	14
Sep	14	14	0	0	0	28
Oct	2	2	3	0	5	12

[a] F = full, $^3/_4$ F = three-quarter full, $^1/_2$ F = half full, $^1/_4$ F = one-quarter full, E = empty.

Table 2. Average monthly volume of stomach contents in relation to size of fish.

Size of fish (cm)	Volume of stomach contents (mL)	Standard error	Sample size (n)
3.5	0.08	0.027	11
4.5	0.09	0.035	18
5.5	0.08	0.018	38
6.5	0.12	0.021	47
7.5	0.16	0.043	56
8.5	0.30	0.042	76
9.5	0.39	0.092	73
10.5	0.39	0.173	67
11.5	0.43	0.223	14
12.5	1.05	0.233	14
15.5	1.56	0.062	6
21.5	2.53	0.288	175

and $r^2 = 0.93$; SE of slope (S_b) = 0.190; SE of stomach content volume (S_y) = 0.329; and df = 10. Therefore,

[3] Stomach-content volume = $0.002802L^{2.186246}$

where L = standard length of the fish.

Metabolic Rates

The rate of oxygen consumption in relation to the weight of the fish shows a negative exponential relation and is given by:

[4] ln (oxygen-consumption rate) = –0.51097 ln (fish biomass) + 0.164025

and $r^2 = 0.90$, SE of slope = 0.07, SE of oxygen consumption rate = 0.151, df = 6. Therefore,

[5] Oxygen-consumption rate (mg/h per g) = $1.178244W^{-0.51097}$

where W = biomass of fish.

Consumption and Assimilation Rates

Both juvenile and adult fish took about 20 h to fill their stomachs with detritus, and the volumes were similar for both laboratory-fed fish and fish caught in the field.

The amounts of detritus consumed and assimilated by juveniles and adults are given in Table 3. Assimilation efficiencies varied from 35.9 to 70.6%. Larger fish have relatively lower efficiencies than smaller fish.

Detritus Production in Seletar Reservoir

The average (sample size = 4) weekly volume of detritus collected is shown in Fig. 2. Volume collected varied between 346.8 mL/m^2 per day and 802 mL/m^2 per day with an overall average of 547.23 mL/m^2 per day (SD = 37.18, n = 15).

Table 3. Detrital assimilation rate and efficiency of tilapia.

Weight of fish (g)	Weight of detritus consumed (g)	Weight of feces collected (g)	Energy of detritus consumed (J)	Energy of feces collected (J)	Assimilation efficiency (%)
22.2	0.1525	0.1057	898.899	446.943	50.28
24.8	0.1715	0.0732	1 002.637	294.696	70.61
25.1	0.1660	0.0913	978.470	386.058	60.54
27.5	0.1934	0.0896	1 139.973	378.870	66.76
31.5	0.1337	0.0971	788.082	410.580	47.90
292.9	0.2925	0.1700	1 724.118	718.832	58.31
346.0	0.2689	0.2403	1 585.008	1 016.089	35.89
348.2	0.2608	0.1948	1 537.264	823.696	46.42
360.7	0.2958	0.1892	1 743.569	800.018	54.12
389.5	0.3132	0.2406	1 846.131	1 017.360	44.89

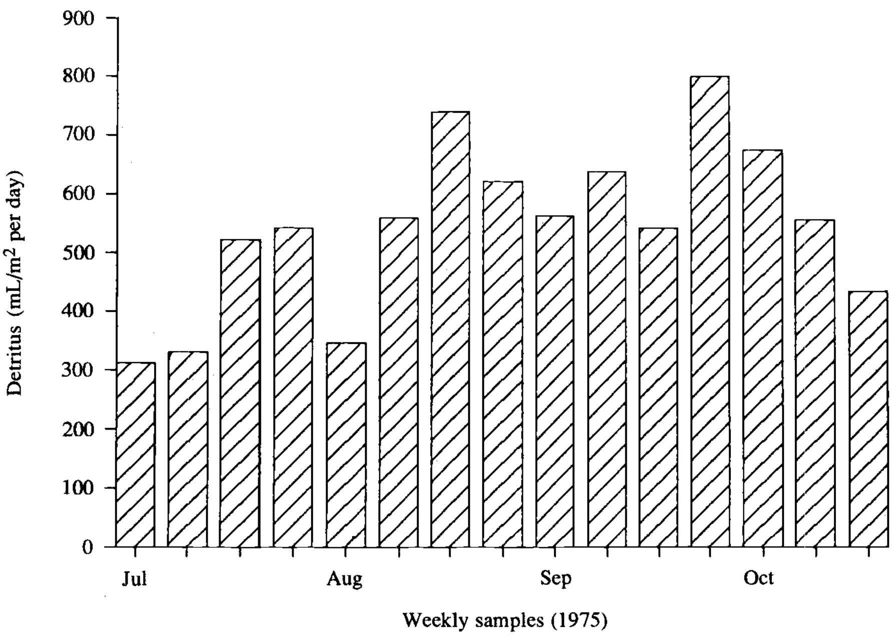

Fig. 2. Detritus production in Seletar reservoir.

The wet weight (*WW*)–volume (*V*) linear relationship of detritus is given by:

[6] $WW = 0.23 + 0.12V$ ($r^2 = 0.72$, df = 13).

The dry weight (*DW*)–volume (*V*) linear relation of the detritus collected is given by:

[7] $DW = -0.13 + 0.07V$ ($r^2 = 0.87$, df = 13)

The dry weight–wet weight linear relation is given by:

[8] $DW = 0.12 + 0.30WW$ ($r^2 = 0.68$, df = 9)

The average dry weight of detritus produced was about 38.16 g/m^2 per day.

C, H, and N Composition of Detritus

The detailed C, H, and N analysis of the detritus showed that there was very little incombustible material. The composition was 9.1% carbon, 2.5% hydrogen, 1.1% nitrogen, 7.1% ash, and 80.3% other combustible material (Table 4). The average detritus production rate in terms of carbon in the reservoir is therefore about 3.47 g C/m^2 per day.

Energy Value of Detritus, Stomach Contents, and Feces

The energy values (in J/g) dry weight of ash-free material were: detritus, 5 894.4 ± 67.8 SE (n = 3); stomach contents, 6 713.2 ± 339.7 SE (n = 3); and feces 4 228.4 ± 193.7 SE (n = 3). The average energy value of detritus produced is therefore about 224.9 kJ/m^2 per day.

Population Biology of *O. mossambicus* in Seletar Reservoir

The stock assessment and population characteristics of *O. mossambicus* in Seletar reservoir have been described by Khoo (1983). It was found that the population consisted of a cohort of fast-growing juvenile fish (<15 cm standard length) and a group of slower-growing adult fish (15–25 cm). The estimated natural mortality was about 0.021 to 0.030 on a daily basis. Spawning occurs year-round with a peak between June and September. From mark–recapture studies, the population estimate of the juvenile population in the reservoir was about 10.25 million (95% confidence limits, 8.79–12.28 million). For adult fish, the estimate was about 4.7 million (95% confidence limits, 3.04–10.42 million).

The length–frequency distribution of the fish population as estimated from the carcass method is given in Table 5. Using stomach content volumes measured in relation to fish size as the amount of detritus consumed per day by that size fish (because it took almost 20 h to fill the stomach), the weighted average amount of detritus consumed per day by an "average" fish was calculated to be 0.010 593 g C/fish.

Table 4. Composition of detritus (%).

Sample number	C	H	N	Ash	Combustible matter
1	9.16	2.52	1.04	6.94	80.34
2	9.13	2.46	1.08	7.16	80.26
Mean	9.14	2.49	1.06	7.05	80.30
SD	0.02	0.04	0.03	0.16	0.06

Table 5. The length–frequency distribution (%) of tilapia population as obtained from measurements of dead fish obtained at weekly intervals along the shore of the reservoir from July to October 1975, and the calculated weighted average stomach volume (n = 1 105).

Size-class (standard length, cm)	% frequency	Calculated stomach volume (mL)	Weighted stomach volume (ml)
7.5	0.995475	0.229386	0.228400
8.5	2.352941	0.301582	0.709768
9.5	7.782805	0.384602	2.993972
10.5	5.701357	0.478673	2.729710
11.5	4.977375	0.584002	2.907462
12.5	3.167420	0.700782	2.220180
13.5	2.262443	0.829193	1.876431
14.5	1.538461	0.969402	1.491729
15.5	3.529411	1.121569	3.959383
16.5	2.895927	1.285841	3.724555
17.5	6.787330	1.462362	9.927805
18.5	7.239819	1.651266	11.95760
19.5	8.325791	1.852683	15.42857
20.5	7.782805	2.066734	16.08866
21.5	9.592760	2.293540	22.00640
22.5	10.04524	2.533213	25.45256
23.5	7.601809	2.785863	21.18243
24.5	5.158371	3.051595	15.74485
25.5	2.262443	3.330511	7.536815

Discussion

Although the detritus produced in the reservoir consisted of only 7% ash material, the assimilation studies showed that only about 50% of the detritus is assimilable by tilapia.

Average assimilation efficiency in juveniles was about 59.2% (SD = 9.95, n = 5) and this decreased to about 47.93% (SD = 8.7, n = 5) in adults. This agrees with observations of Pandian (1967) who found that the rates of feeding, digestion, absorption, and conversion in *Megalops cyprinoides* and *Ophiocephalus striatus* decreased with increasing body weights of the fish.

Similar assimilation efficiencies were obtained for *Tilapia nilotica* in Lake George, South Africa (Moriarty and Moriarty 1973). They found that *T. nilotica* assimilated about 43% of the total phytoplankton ingested during a 24-h day. The range of assimilation efficiency was between 40% and 60%. Bowen (1982) obtained similar assimilation efficiencies for various tilapia species, and for *O. mossambicus* his estimates ranged from 35% to 77%.

These results show that detritus comprises a significant proportion of the tilapias' diet (25% in juveniles and 75% in adult fish). Its availability, production, and utilization would, therefore, determine the standing crop of tilapia in the reservoir.

Detritus was produced mainly from dying or dead plankton organisms that sank. The estimated average volume of detritus collected (547 mL/m^2 per day) is equivalent to 38.16 g dry weight/m^2 per day. With an average carbon content of about 9.1%, the magnitude of detrital production in terms of carbon content was about 3.47 g C/m^2 per day. In terms of energy, the production rate was about 224.9 kJ/m^2 per day. Thus, in 300 ha, the average detritus produced was about 674.80×10^6 kJ/m^2 per day or 10 410 kg C/day.

Based on fish length and its relationship to stomach volume and the percentage length–frequency distribution of the fish population, the average amount of detritus consumed per fish was about 0.010 593 g C/fish per day (Table 5). The population estimate of tilapia in Seletar reservoir by mark–recapture (Khoo 1983) was between 8.79 and 12.28 million (mean = 10.25 million) for juveniles, and between 3.04 and 10.42 million (mean = 4.7 million) for adults. The total number of tilapia in Seletar reservoir is estimated to be about 14.95 million. The estimated amount of detritus required per day to support about 15 million tilapia in the reservoir is, therefore, about 158.895 kg C/day. However, the amount of detritus produced by the reservoir was about 10 410 kg C/day, which is about two orders of magnitude higher than that required by the tilapia population (65.5 times). This shows that a large portion of the detritus was not used to support tilapia. One possible reason is the unavailability of detritus to the fish; another is its use to support species other than fish, such as molluscs.

The usable benthic areas, with accessible detritus that is available to the fish, were mainly less than 6 m deep, situated mainly along the shallow shore. Those areas with depths greater than 6 m will generally be inaccessible to the fish because, for most of the year, the water overlying these areas has an oxygen content below 2 ppm and is, therefore, uninhabitable by aerobic species (Khoo et al. 1977). Only a small area of the reservoir is less than 6 m deep.

Oreochromis mossambicus fed mainly on detritus. No other fish species present in the reservoir was detritivorous (Khoo 1983). Other fish species present were in lesser numbers are the planktivores such as *Hypophthalmichthys molitrix* and *Aristichthys nobilis*, and the macrophytic herbivores such as *Ctenopharyngodon idellus*. Predators include *Oxyeleotris mamoratus*, *Channa micropeltes*, *C. striatus*, *Acentrogobius reichei*, *Clarias batrachus*, and *Anabus testudineus*. Omnivorous aquarium fishes such as *Poecilia reticulatus* are abundant in shallow parts near the shore. Nevertheless, *O. mossambicus* is probably the main fish consumer of detritus in Seletar reservoir.

Oreochromis mossambicus is suitably adapted to feed on detritus (Bowen 1982). It possesses morphological and physiological adaptations to use this diet. *Oreochromis mossambicus* is, therefore, the opportunistic fish species that functions as the detritivore in the Seletar reservoir ecosystem. This species thus helps to convert dead and decaying detritus into useful fish protein. The encouragement of such detrital feeding species may help to "clean-up" the reservoir, that is, to remove organic matter that will otherwise be remineralized and return to the water. *Oreochromis mossambicus* is undoubtedly the most suitable species for this role as a detritivore, as is also shown by its predominance in the Seletar reservoir ecosystem.

The detrital materials produced in Seletar reservoir are very substantial and are more than sufficient to support the existing detritivorous fish population. A large proportion of the unused detritus probably sinks to, and accumulates at, the bottom of the impoundment. The only other probable and major consumers of the detritus resource are the species of molluscs, *Melanoides tuberculata*, *Pila scutata*, and *Lymnaea rubiginosa*, which were very abundant in the shallow areas. Their abundance, and hence their degree of detritus utilization and role in the reservoir, however, is not known and information regarding their population biology is needed for a better understanding of the bioenergetics of Seletar.

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Discussion: Section 1 — Limnology

The discussions revolved around three major points: first, collection of limnological data; second, reservoir classification from a fisheries point-of-view; and, third, success or failure of *Oreochromis mossambicus* in south Asian reservoirs.

It was noted that considerable research effort was expended on collation of limnological data, even when the primary research objective was fish production. Moreover, such data remain underutilized because of lack of facilities and the know-how for performing multivariate analysis. The need to define parameters (limnological) that are likely to be of use as fish-yield predictors or in management, as opposed to detailed limnological study, was pointed out. It was agreed that a few parameters measured accurately and more frequently are of better value than a large number of parameters measured with lesser precision and frequency.

The use of the light–dark bottle method for estimating primary production was discussed. It was agreed that this method was useful, especially because of the lack of facilities in most countries to use isotopic techniques for primary-production estimation. It was also pointed out that the dark bottle measurements by themselves could be considered as good indicators of microbial respiration, and that attempts should be made to evaluate their relationship to fish yield, as has been done for aquaculture ponds.

The need to evolve a classification for reservoirs from a fisheries management point-of-view was discussed. It was thought that subjective criteria based on average yield, as well as those classifications adopted by reservoir management authorities — mostly irrigational and hydroelectric — will not be adequate for comparative studies and for developing management strategies. It was felt, however, that the information that is now available is insufficient to evolve such a classification and that all scientists should attempt to provide as much information as possible and collectively strive to arrive at a plausible classification in the near future.

The lack of effective coordination between fisheries scientists and reservoir management personnel, except perhaps in the People's Republic of China, was discussed. The isolated instances such as the Satanur Dam in India where coordination has been brought about in water-level regulation and has had a positive influence on spawning migration of the Indian major carp, *Catla catla*, was cited as an example that such practices could be evolved in conjunction with irrigation authorities. It was felt that a primary reason that we are unable to establish such effective water-management policies, in conjunction with reservoir authorities, was the lack of adequate information on aspects of the biology of the major species contributing to a fishery, particularly their spawning habits and migrations.

The success of *O. mossambicus* (Peters) in south Asian reservoirs was briefly discussed. It is evident that this species is getting "displaced" in a number of reservoirs by *O. niloticus* (L.), which is thought to be a more desirable species because of its better rate of growth and consumer acceptability. The reasons for this phenomenon are, however, little understood. A plausible reason could be "basin shape"; the shallower basins being favourable for *O. mossambicus* and the deeper ones for *O. niloticus*. It was also agreed that for most tilapia species, apart from the "initial seeding," continuous stocking is not needed to sustain a fishery.

The question of exotics was briefly addressed. The consensus was that the number of species available in most countries, indigenous and exotics, was adequate and that there was no urgent need to consider further introductions.

The paper on Thale Noi Lake, Thailand, not a reservoir but a natural lake, was considered as an example of a fruitful use of an aquatic macrophyte to enhance fish production and to act as a means of controlling the spread of an aquatic weed that hinders both fish production and other uses of the water, such as transportation. It was thought that this approach might also be considered for reservoirs.

The role of detritus as a food–energy source in the reservoir ecosystem was discussed. It was pointed out that there is a school of thought in some countries that detritus plays only a very insignificant role in enhancing fish production. To the contrary, it was pointed out that there is a great deal of scientific literature to show that detritus plays an important role in energy transfer, particularly in tropical aquatic systems.

It was agreed that there was a dearth of knowledge on the role of nanoplankton in energy transfer in reservoirs, and that such studies, combined with those on detritus, would provide further insight.

Section 2 —

Postimpoundment Changes

A Malaysian Tidal Barrage Incorporating a Fishery Component: Perspectives

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Tidal barrages act as drainable dams at lower, estuarine, reaches of eight Malaysian lowland rivers. Multipurpose barrages form semipermanent reservoirs during the dry season and ensure that water levels are maintained at specific levels. The impact of tidal-barrage development on the decrease in fish stocks could be indirectly due to its impact on water-quality status, sedimentation, hydrology, and tidal regimes. Its direct impact may be due to declines in biological production processes, a decrease in ichthyoproductivity in saline conditions, nutrient deficiency, the obstruction of fish migration between ecosystems, stress and mass mortalities associated with abrupt downstream discharge, overfishing, and, possibly, drawdown effects. These effects are summarized in this paper.

Design and operational procedures for tidal barrages should maximize the volume of water entering on each tidal cycle to disperse sediments, nutrients, and pollutants, and import as much oxygen as possible, thereby decreasing the residence time and increasing biological production and biomass. Maximizing fish production in a tidal barrage by an integrated management approach is suggested. A survey of the Krian barrage is presented, to explore the hydrological requirements for fisheries development at tidal water-supply barrages. Desirable design and operational features are recommended.

The construction of tidal barrages is proceeding at a rapid rate in Malaysia because of the need to prevent saline-water intrusion into the estuarine reaches of low-lying rivers. Eight tidal barrages have been constructed in Malaysia (Table 1).

Most studies on the hydrological conditions and ecological aspects of tidal barrage developments have been conducted in the temperate region (Hoare and Haggett 1979; Hockin and Parker 1988). Moreover, only very limited data are available on the fisheries and the ichthyofauna at barrage structures. This is because the design and operational procedures for tidal barrages are mainly defined to serve their primary functions of freshwater supply and the prevention of saline-water intrusion. The fishery component is an accidental or secondary function. The construction of barrages in tidal habitats in Malaysia has caused conflicts with fishery interests (EEC/SI 1985; MOA 1989), particularly downstream from the barrage. This study focuses on the Krian barrage, which has substantial commercial and recreational fisheries, to explore the hydrological requirements for fish production at tidal barrages.

Table 1. Malaysian floodplain rivers impounded with tidal barrages.

Characteristics	Floodplain rivers							
	Perlis	Kedah	Muda	Prai	Krian	Malacca	Kesang	Scudai
Tidal reach prebarrage (km from river mouth)	16	37	30	22	26	13	21	17
Tidal barrage (km from river mouth)	14	13.2	10	10	14	8	7	12
Purposes of tidal barrage:								
Prevention of saltwater intrusion	+	+	+	+	+	+	+	+
Prevention of tidal intrusion and flooding	+	+	+	+	+	+	+	
Irrigation intake					+[a]			
Water-supply intake					+[b]	+		+[c]
Residence time (days) when gates closed					7–35	0.5–35[d]		
Fisheries activities	—[e]	—	+[f]	—	+[g]	+[h]	—	—
Fishing boats (licenced)	155	—	551	—	223	575	—	352
Outboard	154	—	492	—	203	516	—	311
Nonpowered	1	—	59	—	20	59	—	41
Siltation rate (m^3/year)[i]	S	P	D	130 000	B	M	H	H
Navigation problems	—	+[j]	+[j]	—	+[k]	—	—	—

[a] At Bogor pumphouse.
[b] At Lubok Buntar for Pensang's need.
[c] At Public Utilities Board, Singapore.
[d] Average flow and low flow values.
[e] No information or records.
[f] Estuarine catch forms 53% of total (i.e., 5 000 t) at Muda River.
[g] Important in rural economy; Krian's Department of Fisheries management inputs enhance estuarine fisheries.
[h] Marine catch forms 2 445 t; collection of shellfish and processing of fisheries products at Malacca River mouth.
[i] S = slight; P = progressive; D = sand dune drift and migration; B = high siltation resulting in 3-m sandbar at the Krian River mouth; M = moderate; and H = high.
[j] Not navigable at spring low tide at river mouth (Kedah and Muda respectively).
[k] Fishing boats have difficulty navigating through Krian River mouth.

Krian Barrage

The Krian River basin covers the northern portion of Malaysia and has a population of about 190 000 in a catchment area of 1 418 km^2. Domestic sewage from the main townships (Parit Buntar, Bandar Baru, and Nibong Tebal) situated around lower reaches pollutes the Krian River. Agroindustrial activity causes siltation or sedimentation of the river bed and bioaccumulation and biomagnification of organochemicals (Yap and Ong 1990). The existence of the Krian barrage about 14 km from the mouth of the Krian River appears to have aggravated pollution and siltation downstream.

Krian barrage is a five-bay open-flume structure fitted with electrically operated roller gates. Each of the five gates can be operated independently. The base of the barrage consists of a concrete slab at –3.66 m RL (reservoir level).

The Krian tidal barrage has been operational since 1976 and keeps saline water away from the irrigation-water intake at the Bogak pump house, maintains a minimum pond level at the intake during pumping periods, prevents high surge tides from causing flooding, and facilitates the abstraction of additional water to augment the Bukit Merah reservoir supply during the dry season. The barrage is fully closed when the water levels of the Krian River fall below 0.6 m RL, and when the water levels exceed 1.0 m RL to prevent saline-water intrusion upstream. The barrage is at least partially open most of the time during the flood season. It is, however, rarely fully opened. When closed, the top of the gates are at 2.44 m RL. The total stored volume behind the barrage is 16×10^6 m^3, and the active storage is 3×10^6 m^3.

Materials and Methods

Fisheries Resource Appraisals

Fisheries resource appraisals were carried out by field observations and surveys during 1988/89 on catches and the income of fishermen and of traders at two landing sites.

Fish species composition upstream and downstream of the Krian barrage were recorded. Published data on fish composition (Jothy et al. 1983; Mohsin and Azmi 1983; Zakaria 1983) and unpublished data from files of the Department of Fisheries (Krian District) and Yap (1978–1987, unpublished) were incorporated. Fish assemblages of the Krian Barrage were compared with information from the undisturbed lower river reaches of nearby Kurau River, Perak, Malaysia (Yap 1982).

A total of 680 fish specimens (>10 cm standard length) and 54 freshwater prawns (*Macrobrachium rosenbergii*) were obtained from commercial catches on 14–15 January and 1–3 February 1989. The trophic status of 36 species exploited by commercial fishermen was determined using the statistical approaches described by Yap (1988).

Ecological Impact Analyses on the Krian Barrage Development

Impact analyses compared the pre- and postbarrage conditions (1978–1989). Project planners were interviewed and baseline data, project documents, files, and scientific publications were examined. Whenever data were unavailable, a combination of approaches was applied:

- Follow-up interviews and field visits conducted over a 4-month period in 1988–1989;
- Approximations based on observations of the existing environment or on trends from the available water quality sampling data; or
- Perceptions and guidelines from other similar studies.

Water Quality

Water and soil qualities at the cockle (*Anadara granosa*) bed off Krian estuary have been evaluated by the Malaysian Fisheries Development Board since 1983. Three sampling points at Sungai Udang Besar (0.96 km from the river mouth), Nibong Tebal (10.56 km), and Parit Buntar-Bandar Baru (16.96 km) have been monitored by the Malaysian Department of Environment (DOE) since 1978. Seven other sampling stations in the vicinity of Krian barrage were also established (in 1988 and 1989) and water samples at different depths were collected and analyzed (MOA 1989).

Important water-quality parameters in the study area were assessed and compared with the national water-quality criteria and interim standards set for Malaysian river basins (Yap et al. 1988). Trends in the changes in water quality were determined by applying the DOE water-quality monitoring data for 1979–1985 to a water-quality index system (Yap et al. 1988). The water-quality index (WQI) is described by the formula:

[1] $WQI = \Sigma I_i W_i$

where I_i = the subindex of each parameter i and W_i = the weighting factor for each parameter i.

The index is based on five parameters (biological oxygen demand (BOD), chemical oxygen demand (COD), pH, ammonia-nitrogen, and suspended solids) with weighting factors (W) of 0.24, 0.21, 0.21, 0.15, and 0.19, respectively, assigned to each parameter (DOE 1990).

Hydrological Conditions, Sedimentation, and Operational Procedures of Krian Barrage

Historic information on the sedimentation rate and hydrological characteristics of Krian River, and records for operational procedures of Krian barrage were extracted from the Ministry of Agriculture (MOA 1988). Important inputs in the model's simulation are: tailwater levels, river cross-sections, flood hydrographic data, and hydraulic parameters. Broadly two mathematical models were used: first, an unsteady state model (STIDE), which considers tidal levels downstream of Krian barrage; and, second, a steady state model (HEC2), which considers a generally accepted high water level of 1.4 m at the barrage and upstream of Krian barrage.

Table 2. Schedule of fry stocking and release sites at Krian River and Krian Fisheries District, 1981–1988.

Release site	Species	Fry stocked (in '000) per year								Total
		81	82	83	84	85	86	87	88	
Alor Pongsu (Krian River)	*Puntius gonionotus*	5	5	—	10	—	—	40	—	60
	Macrobrachium rosenbergii (prawn)	—	—	—	—	—	—	100	—	100
Samagagah (Krian River)	*Puntius gonionotus*	15	15	10	40	15	—	—	—	95
Muara Bagan Tiang (Krian estuary)	*Penaeus monodon*	—	—	—	—	—	100	130	150	380
	Panaeus merguiensis	—	—	—	—	110	—	—	—	110
Muara Tg. Piandang	*Penaeus monodon*	—	—	—	—	—	100	—	—	100
Muara Kuala Kurau	*Penaeus monodon*	—	—	—	—	20	—	—	—	20
	Penaeus merguiensis	—	—	—	—	90	—	—	—	90

Source: DOF, Krian, Malaysia, personel communication.
Note: Freshwater fish and prawn 255 000 fry; brackish-water prawns 700 000 fry.

Results and Discussion

Fishery Resource Appraisals

Fisheries, Aquaculture Operations, and their Returns

Freshwater and saltwater fish as well as shellfish in the vicinity of Krian barrage are harvested and cultured commercially for subsistence trading and for local consumption. Several fisheries and aquacultural management techniques have been implemented by the Department of Fisheries (Krian District), the Malaysian Fisheries Development Board, and private enterprises to enhance stocks, and to stabilize yields. These activities include: fish and prawn fry stocking upstream of Krian barrage and in the Krian estuary and adjacent estuaries; cockle culture on mud flats; and cage culture in coastal waters within the Krian Fisheries District.

Fry Stocking: About one million fish and prawn fry were stocked at sites in the vicinity of Krian barrage and in the Krian estuary (Table 2). Commercial exploitation of Krian River fisheries is concentrated further downstream.

Cockle Culture: Cockle culture is the most important coastal aquaculture in the rural economy of the Krian Fisheries District. At present, 53 cockle farms/culturists are in operation, and occupy an area of 697 ha of mud flats. There are three farms at Bagan Tiang and nine farms at Kuala Kurau.

Cage Culture: Cage culture of saltwater fish (e.g., *Lates calcarifer*, *Lutjianus johni*, and *Ephinephelus* spp) is operated by 23 culturists who have 1 346 cages occupying an area of 12 500 m^2 at Kuala Kurau.

Economic Benefits: A preliminary assessment in January–February 1989 revealed that existing fisheries development and aquaculture operations in the vicinity of Krian barrage have considerable economic benefits. Freshwater prawns contribute about 308 000 MYR/year (Table 3) and brackish-water prawns, cockles, and cage culture contribute about 34.5 million MYR/year (2.63 Malaysian ringgits (MYR) = 1 United States dollar (USD)).

Fish Composition

In relation to the salinity gradient, groups of fish and prawns live in proximity to the Krian barrage producing a longitudinal "zonation" of species. Broadly, there are three zones: freshwater; freshwater–saltwater interface; and coastal-marine waters. The species richness in these zones is freshwater — 14 fish species dominated by the family Cyprinidae; freshwater–saltwater interface — 20 fish species and 1 prawn; and coastal-marine waters — 28 fish species dominated by the family Carangidae, 2 penaeids, and 3 molluscs (appendix).

The number of freshwater species recorded is lower than that recorded from the adjacent Kurau River (20 species from the Bukit Merah reservoir spillway; Yap 1982) and the 40 species from the nearby Perak River (Yap et al. 1988). The species richness of 20 estuarine fishes is attributable to the influence of saltwater and the relatively flat terrain at Krian barrage. The Krian estuary is characterized by tidal channels, intertidal areas, salt marshes, and mangrove stands. These water-filled depressions and wetlands provide rich habitats for fishes and prawns. There has been a general shift in catch composition in favour of brackish-water fishes and prawns in the vicinity of Krian barrage, particularly *Megalops*

Table 3. Estimate of gross returns from sale of fishery products.

Products	Number of boats or families	Fishing days/year	Unit price (MYR)	MYR/ day	MYR (000)/ year
Freshwater prawn					
Krian barrage upstream	30	288	10	1 050	302.4
Krian barrage downstream	5	288	10	20	5.76
Brackish-water prawns					
Muara Kuala Kurau	450	365	35	79 000	29 000.0
Cockle					
Krian Fisheries District	53	—[a]	0.304[b]		166.0
			0.62[c]		336.0
Cage culture					
Krian Fisheries District	23	—[d]	5[e]		5 000.0
			8–22[f]		(net)

Note: 2.63 Malaysian ringgits (MYR) = 1 United States dollar (USD).
[a] 7-month cycle.
[b] Wholesale.
[c] Retail.
[d] 8-month cycle.
[e] Sea bass.
[f] Grouper.

cyprinoides (ox-eyed herring), *Lates calcarifer* (sea bass), *Tetraodon* spp (puffer fish), and the freshwater prawn.

Trophic Status of Exploited Fish and Prawn

The trophic levels of 35 fishes and 1 prawn sampled in the vicinity of Krian barrage are given in Table 4. The species from the commercial catch at Krian barrage are planktivorous, herbivorous, detritivorous, omnivorous, carnivorous (pelagic), carnivorous (benthic), and piscivorous. The dominant species in the catches are carnivores (44% of the catch) and piscivores (20%). It is important to note the absence of planktivores and their predators in the Krian estuarine and coastal ecosystems.

Ecological Impacts

Although an impoundment in the vicinity of an estuary can be visualized as causing "concentration and/or dilution" effects and biological effects (Bernacsek 1984), what remains is that little is known whether it is the presence of the tidal barrage, operational procedures of the tidal barrage, or a combination of both that has an impact on the overall ecology. The ecological impacts of a tidal barrage are related to water quality, sedimentation, and hydrological conditions in the immediate vicinity (Fig. 1).

Impact on Water Quality

Water quality in the 14-km river stretch is primarily influenced by saline water; however, local effects of freshwater sources upstream occur. Salinity declines from

0 to 12‰ at the cockle bed station to 0.78‰ at the barrage. The Krian River mouth is highly stratified, with incomplete vertical mixing.

Values of most ionic constituents at Krian barrage are within the acceptable safety limits for the protection of aquatic life and its users (Table 5). However, there are two exceptions. Levels of ammonia-nitrogen, total-nitrogen, and biochemical oxygen demand (BOD) are generally higher in the more populated areas of the three towns. The BOD is higher in the immediate vicinity of the barrage. This is particularly so downstream of the barrage where the waste discharge was polluted with raw sewage, rice-mill waste, timber-mill wastes, and fecal matter from hanging latrines. The higher BOD level upstream of the barrage is a result of effluent discharge from an industrial estate. As well, significantly higher concentrations were recorded for suspended solids, mercury, oil, and grease. Suspended solids are excessive at Kampong Sungai Udang Besar (11 258 mg/L), Krian River mouth (27–891 mg/L), Nibong Tebal (674–1 701 mg/L), and downstream of Krian barrage.

The levels of mercury detected at Nibong Tebal (0.08 mg/L) and Bandar Baru (0.12 mg/L) are dangerous for aquatic life. The recommended national standards are 0.0001 mg/L as a 24-h average concentration and 0.004 mg/L as a maximum concentration. However, further analysis of the data and communication with DOE personnel indicated that mercury was detected only at Nibong Tebal and Bandar Baru. Thus, the mercury pollution problem is a localized one. High concentrations of oil and grease were recorded at Kampong Sungai Udang Besar (4.00 mg/L), Nibong Tebal (0.22 mg/L), and Bandar Baru (0.92 mg/L).

The MOA (1989) and DOE water-quality monitoring program (1978–1984) at Krian River indicated microorganism abundance and contamination. The most important bacteria discharged directly to the Krian estuary are *Escherichia coli*. Spatially, fecal coliform counts were not at dangerous levels (an average of 18/mL, ranging from 8 to 24/mL) at the river mouth and at Nibong Tebal; but the counts increased to 125–429/mL at the barrage and Bandar Baru. Higher coliform counts occurred during low flows (barrage closed), and low counts occurred during high flows (barrage opened). The DOE data indicated *E. coli* at 85 800 most probable number (MPN)/100 mL and coliform at 62 700 MPN/100 mL, attributable to domestic sewage at Nibong Tebal. Thus, microorganism contamination exceeded the national criteria for shellfish culture-and-harvest waters, which is a median 14 MPN/100 mL for fecal coliforms, with not more than 10% of samples exceeding 43 MPN/100 mL. High *E. coli* counts were clearly the result of direct discharge of fecal wastes from towns, hanging latrines along the river banks, and runoff contaminated by septic tank discharges. It was also attributable to the higher residence time of domestic sewage trapped by the barrage.

The water quality index (WQI) values show a discernible longitudinal pattern. At Kampong Sungai Udang Besar, WQI was 64.6. It improved gradually to 74.2 at Nibong Tebal and to 75.6 at Bandar Baru. Therefore, sites downstream of Krian barrage are more polluted than those upstream.

It is difficult to quantify the effect that the Krian barrage has had on water quality from the present observations or from the available sampling analyses (1978–1989) because no comparable water-quality figures are available from before the barrage was built. However, the effects on water quality can be approximated from postbarrage accounts and from information from similar studies else-

Table 4. Trophic classification (+) of fish and prawn from Krian River basin.

Zone and species	Trophic classification						
					Carnivore		
	Planktivore	Herbivore	Detritivore	Omnivore	Pelagic	Benthic	Piscivore
Freshwater							
Trichogaster pectoralis	+	.	.	.	.	.	.
Mystus vittatus	.	.	.	.	.	+	.
Clarias batrachus	.	.	.	+	.	.	.
Labiobarbus festiva	.	.	+	.	.	.	.
Osteochilus hasselti	.	+	.	.	.	.	.
Puntius gonionotus	.	+	.	.	.	.	.
Puntius schwanenfeldii	.	.	+	.	.	.	.
Ophicephalus striatus	.	.	.	.	.	.	+
Scleropages formosus	.	.	.	+[a]	.	.	.
Ompak bimaculatus	.	.	.	.	+	.	.
Freshwater–saltwater interface							
Ambassis gymnocephalus	.	.	+	.	.	.	.
Lates calcarifer	.	.	.	.	.	.	+
Ilisha elongata	.	.	.	+	.	.	.
Setipinna breviceps	.	.	.	+	.	.	.
Periophthalmodon schlosseri	.	.	.	.	.	+	.
Macrobrachium rosenbergii (prawn)	.	.	.	+	.	.	.
Megalops cyprinoids	.	.	.	.	.	.	+[b]
Tachysurus caelatus	.	.	.	.	.	+	.
T. sagor	.	.	.	.	.	.	+
Tetraodon kretamensis	.	.	.	.	.	.	+[b]
Toxotes jaculatus	.	.	.	.	.	+	.

Coastal waters and marine							
Caranx malabaricus	.	.	.	.	+	.	.
Selar boops	.	.	.	.	+	.	.
Selaroides leptolepis	.	.	.	.	+	.	.
Chirocentrus dorab	.	.	.	.	.	+	.
Cynoglossus lingua	.	.	.	.	+	.	.
Lutianus johnii	.	.	.	.	+	.	.
Mugil sp.	.	.	+	.	.	.	.
Plotosus canius	.	.	.	.	.	.	+
P. anguillaris	.	.	.	.	.	+	.
Polynemus tetradactylum	.	.	.	.	.	+	.
Rastrelliger kanagurta	.	.	.	.	.	+	.
Johnius sina	.	.	.	+	.	.	.
Parastromateus niger	.	.	.	.	+	.	.
Saurida tumbil	.	.	.	.	.	.	+
Trichiurus haemela	.	.	.	.	+	.	.
Total number of species	1	2	4	6	8	8	7
Percentage	3	5	11	17	22	22	20

Note: Gut contents sampled by Yap, S.Y., 14–15 January and 1–3 February 1989.

[a] Fruits/seeds and teased insects in the gut contents analyzed.

[b] Feeds predominantly on fry of prawn.

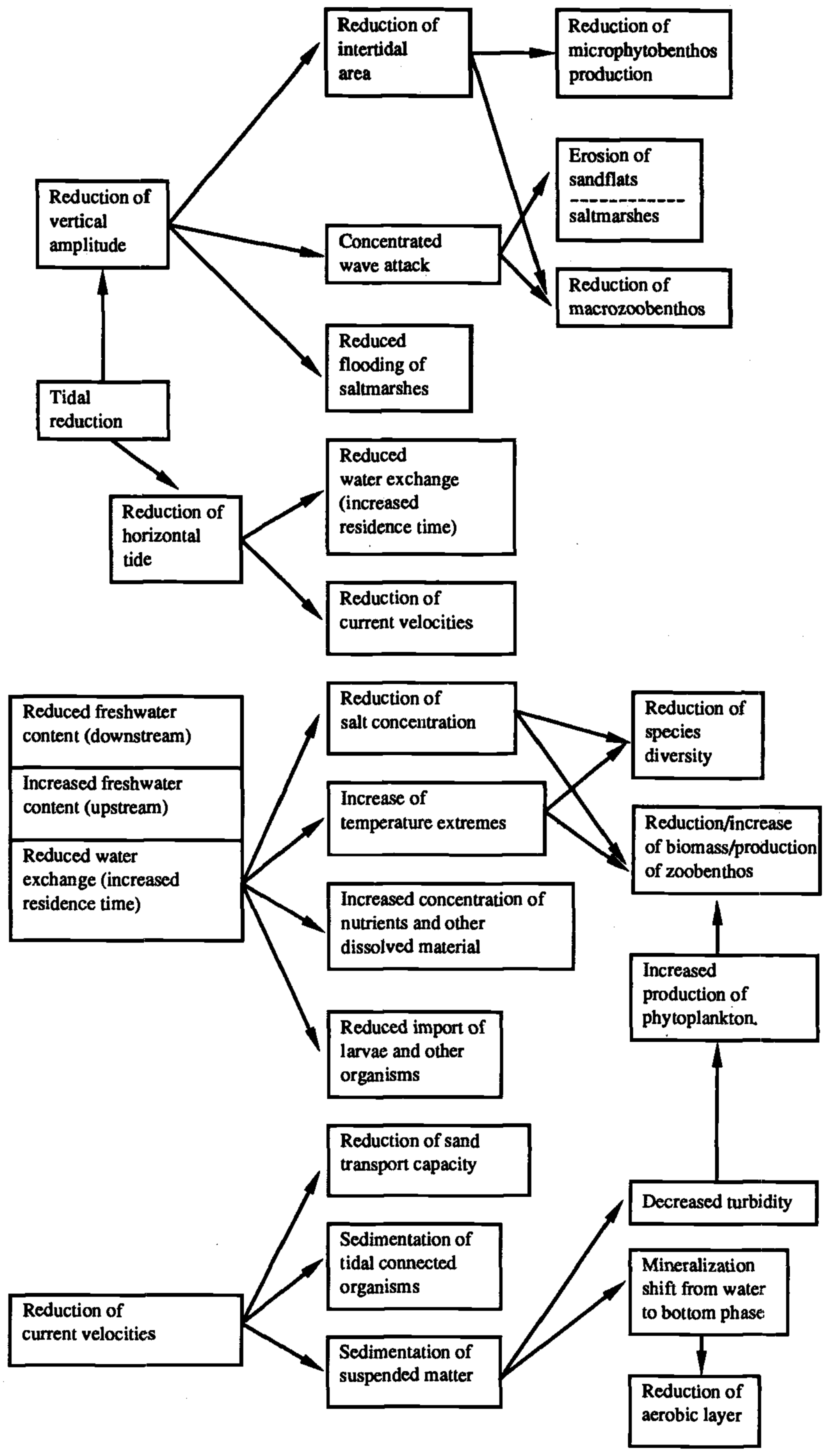


Fig. 1. Effects of tidal reduction and decreased freshwater content on an estuary.

Table 5. Summary of water quality downstream and upstream of Krian barrage (mean values with ranges in parentheses).

Parameter	Criteria (Yap et al. 1988)	National project scheme: Bagan Tiang cockle bed (LKIM 1983)	Krian River mouth (MOA 1988)	Sg. Udang Besar (MOA 1988)	Sg. Udang Besar (DOE 1978–84)	Nibong Tebal (MOA 1988)	Nibong Tebal (DOE 1978–86)	Barrage (MOA 1988)	Bandar Parit (MOA 1988)	Baru-Buntar (DOE 1978–84)
Dissolved O_2 (mg/L)	7 (mean) 2 (min)	(1.1–4.8)	3.76 (2–5)	3.66 (3–5)	4.65	3.94 (3–6)	4.12	4.47 (4–6)	4.36 (3–6)	4.53
Saturated O_2 (%)	—	—	76.1 (39–109)	71.0 (59–101)	—	73.4 (46–121)	—	82.2 (72–110)	80.5 (52–118)	—
Salinity (‰)	—	(0–12)	10.7 (0–30)	7.20 (0–20)	12.4	1.41 (0–21)	21.3	0.78 (0–1.2)	0.30 (0–1.9)	0.00
Water temperature (°C)	normal ±2	28.0	29.6 (27–33)	29.7 (27–38)	25.4	28.6 (26–32)	28.0	27.9 (27–28)	28.8 (27–32)	27.7
Turbidity (NTU)	—	35 cm transparency	—	—	90.0	—	17.8	—	—	10.0
pH (in situ)	6.5–9	7.10	6.86 (5–8)	6.70 (5–7)	6.61	6.22 (6–7)	5.57	5.95 (5.9–6)	6.20 (5–7)	5.76
Biological oxygen demand (5 days)	5	(2.43–3.03)	1.98 (0.05–5)	—	0.96	1.75 (0.1–6)	10.6	1.35 (0.6–3)	1.48 (0–4)	16.96
Total suspended solids (mg/L)	80	(15–61.3)	311 (27–891)	182 (18–346)	11 258	180 (3–1 701)	674.4	40.5 (12–74)	27.6 (9–91)	70.8
Suspended organic solids (mg/L)	—	(10–13.3)	—	—	—	—	—	—	—	—

(continued)

Table 5 concluded.

Parameter	Criteria (Yap et al. 1988)	Bagan Tiang cockle bed (LKIM 1983)	Krian River mouth (MOA 1988)	Sg. Udang Besar (MOA 1988)	Sg. Udang Besar (DOE 1978–84)	Nibong Tebal (MOA 1988)	Nibong Tebal (DOE 1978–86)	Barrage (MOA 1988)	Bandar Parit (MOA 1988)	Baru-Buntar (DOE 1978–84)
		National project scheme								
Hardness (mg/L $CaCO_3$)	—	—	—	—	1 205	—	140.3	—	—	17.2
Alkalinity (mg/L $CaCO_3$)	>20	—	—	—	—	—	130[a]	—	—	—
Ca (mg/L)	—	—	—	—	156	—	18.6	—	—	6.33
K (mg/L)	—	—	—	—	—	—	1.54[a]	—	—	—
Mg (mg/L)	—	—	—	—	219	—	31.5	—	—	0.80
Na (mg/L)	—	—	—	—	1 650	—	16.8[a]	—	—	2.10
NH_3 (μg/L)	20	—	—	—	240	3.65 (3–4)	140	2.85 (1–5)	1.30	100
Total N (mg/L)	—	—	1.0 (0.8–1.2)	—	—	0.77 (0.4–1)	—	0.45 (0.4–0.5)	0.56 (0.4–0.9)	—
Total P (μg/L)	100	—	61.0 (16–106)	—	120	39 (5–98)	60	45.5 (40–51)	26.6 (1–91)	110
SO_4 (mg/L)	—	—	—	—	548	—	33.2	—	—	15.4
Al (mg/L)	—	—	—	—	—	—	0.34[a]	—	—	—
B (mg/L)	—	—	—	—	0.15	—	—	—	—	—

Cd (mg/L)	0.0007 (0.0011)[b]	—	nd	—	0	nd	0	nd	nd	0
Cu (mg/L)	0.008 (0.012)[b]	—	nd	—	0.05	nd	0.01	nd	nd	0
Fe (mg/L)	1	(0.19–0.25)	0.35 (0.3–0.4)	—	0.45	2.17 (2–3)	0.50	1.0 (0.9–1.1)	1.0	0.29
Pb (mg/L)	0.00013 (0.014)[b]	—	nd	—	0	nd	0	nd	nd	0
Mn (mg/L)	0.1	—	—	—	0.04	—	0.03	—	—	0.01
Hg (mg/L)	0.0001 (0.004)[b]	—	—	—	0	—	0.08	—	—	0.12
Zn (mg/L)	(0.35)[b]	—	nd	—	0.04	nd	0.03	nd	nd	0.03
Oil and grease (mg/L)	Free[d]	—	—	—	4	—	0.22	—	—	0.92
Microorganisms (per mL)	14[e]	—	18 (8–24)	—	—	86 (13–400)	85 833[c]	125 (7–400)	429 (2–1 100)	—
Coliform[c]	—	—	—	—	—	—	62 667	—	—	—

[a] LKWK 1986.
[b] At water hardness 50 mg/L $CaCO_3$.
[c] MPN/100 mL (most probable number).
[d] Free from visible layer, discoloration, and deposits.
[e] 10% of samples not exceed 43.
nd = nondetectable level.

where (Leentvaar and Nijboer 1986; Hockin and Parker 1988; Struck 1988; Al-Saadi et al. 1989). Possible effects include: first, modification of the longitudinal salinity distribution at high water; second, increased residence time of any pollutants discharged into the estuary; third, methylation of trace metals (e.g., mercury in the vicinity of Krian barrage) to form more toxic and bioaccumulative organometal complexes (Al-Saadi et al. 1989), which cause the greatest environmental concern in the estuary from a waste-disposal point of view; and, fourth, increased threat from excessive human and industrial sewage discharges because the prolonged stagnant conditions (7–35 days residence time) lessen the flushing and drainage of pollutants from the estuary.

Impact on Sediment Quality

A comparison of the longitudinal bed profile of Krian River from the estuary to the barrage (Fig. 2) surveyed in 1970 (prebarrage condition) and in 1987 (postbarrage condition) indicates that almost 3 m of the Krian River bed is of recent origin. This suggests net siltation or sediment trapping as a result of increased retention of fine sediment within the region of the Krian barrage. Other indirect causes of sedimentation are alterations to the hydrology, tidal regimes, and river channel (Fig. 3).

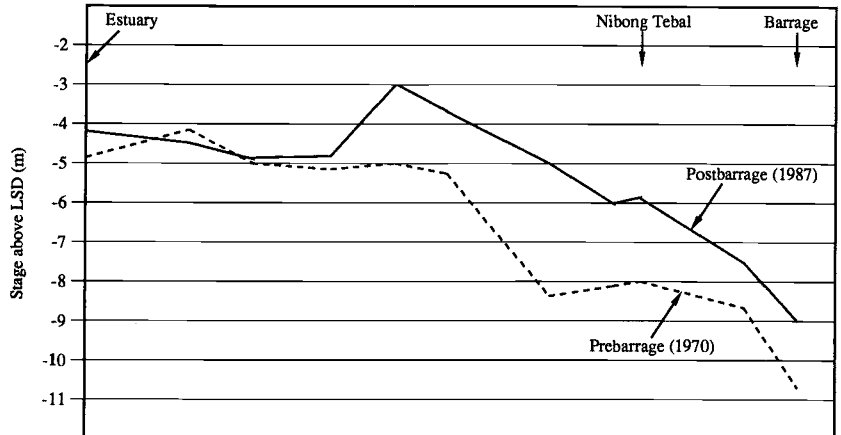
River channel changes will result in increased sedimentation in the vicinity of the barrage. Furthermore, the inevitable increase in salinity causes flocculation of suspended sediment. Flocculation followed by sedimentation tends to take place at about the 5‰ salinity zone. This accounts for the heavy siltation downstream of the Krian barrage and upstream of Sungai Udang Besar that was observed in a recent survey conducted under dry-season low-flow conditions.

Impact on Biological Production and Ichthyofauna

Changes to the hydrology (particularly tidal regimes), water quality, sediment quality, and chemistry of the affected habitats will have repercussions on the biota. In particular, changes in sediment quality and quantity may have implications for the invertebrate community (e.g., coping with smothering and injuries to respiratory systems). In general, the shift and decrease in the tidal range that accompanies barrage development affects the frequency of inundation of the intertidal zones, and might influence the distribution of benthic communities (microbenthos, meiobenthos, and macrobenthos).

Depending on freshwater inputs, tidal flushing, and current mixing, the estuarine ecosystem may experience a transition from: first, brackish to more freshwater conditions; or, second, freshwater to more saline conditions. In theory, any local effects of the barrage leading to a transition from brackish to more freshwater should not necessarily result in a change in biological productivity of the ecosystem. However, a transition in the opposite direction to more marine conditions might result in a loss in productivity (Bernacsek 1984). Although there are no detailed data on the ichthyoproductivity in the vicinity of Krian barrage, the relative abundance of the saline-acclimatized fish (20 species at Krian River compared with 3 species at Kurau River) suggests that a transition to more saline conditions has occurred at the Krian estuary and has possibly resulted in a decrease in ichthyoproductivity.

Impoundment may have produced an indirect impact or change in ichthyo-



Distance (m)	0	1950	3200	4700	5900	6900	8750	9950	10550	12350	13350
Postbarrage bed level	-4.16	-4.45	-4.95	-4.78	-2.99	-3.67	-5.01	-6.05	-5.85	-7.58	-8.93
Prebarrage bed level	-4.78	-4.16	-5.05	-5.16	-5.00	-5.36	-8.34	-8.10	-8.05	-8.66	-10.68

Fig. 2. Longitudinal profile of the Krian River from the estuary to the barrage.

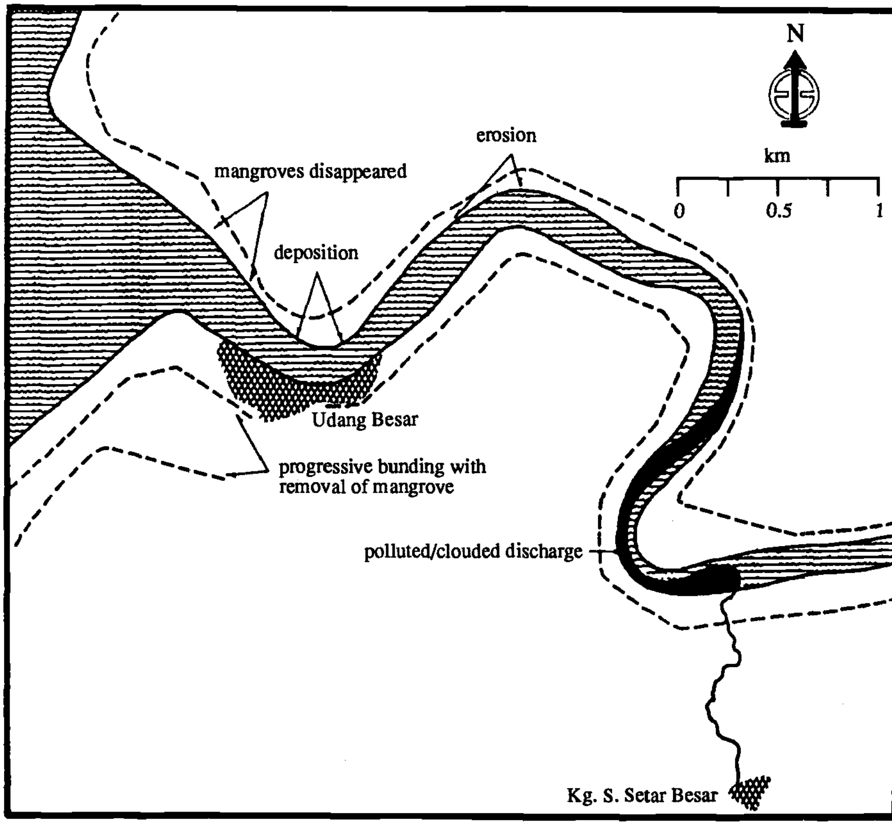


Fig. 3. Summary of channel changes.

productivity in the intertidal areas, salt marshes, and mangrove stands and may, in turn, have affected the fisheries of the freshwater, brackish-water, and coastal zones. The most significant ecological effect will be on the salt marshes and mangrove stands, which will become less susceptible to submergence. These salt marshes and mangrove stands are the nurseries and feeding grounds of fish and juvenile prawn.

The Krian barrage is designed to favour discharge and withdrawal of the hypolimnion (MOA 1988, 1989). The discharge of hypolimnetic water, which may be slightly stratified, polluted, and deoxygenated, downstream and to the estuary may pose problems for forage species.

The trophic classification of fish and spot-checks on four or five fishermen at Nibong Tebal and 20 fishermen at Sungai Udang Besar on 1–3 February 1989 revealed that daily landings are dominated by predatory brackish-water fish species. Trash fish (freshwater puffer fish) and ox-eyed herring are the main piscivores, preying heavily on fry of freshwater and brackish-water prawns. The Krian barrage seems to have both a physical "concentration" effect and biological effects in favour of these predatory fishes (Bernacsek 1984).

When the tidal barrage is operated each day in line with tidal cycles, it is unlikely that the barrage poses a significant "barrier" to migratory fish. During dry weather, however, prolonged closing of the tidal barrage may have an effect on the migration of these fishes.

The decline in freshwater prawn landings at Nibong Tebal–Sungai Udang Besar is reported to be due to overfishing brought about by irregular operation of the Krian barrage. A sudden discharge (abrupt opening of the gates following a complete, prolonged closing of the barrage gates) may prove too stressful to the prawns and ichthyofauna. Prawns responded to this environmental stress by rushing to the surface of the water and to the river edges, making them easy to fish and prey on. Mass mortalities seem to be an inevitable and indirect consequence of irregular operation of the tidal barrage during dry weather conditions.

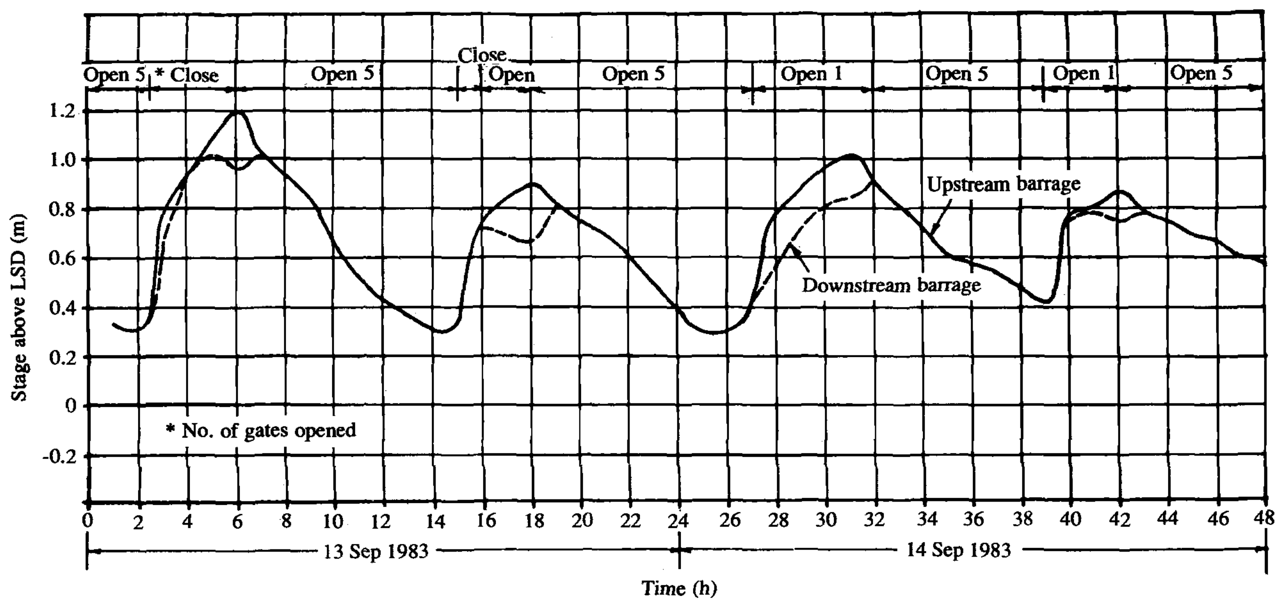
Aquarium fish (dragon fish, *Scleropages formosus*) are caught in abundance upstream of Krian barrage. The species is threatened with extinction due to the intensive illegal fishing (MOA 1988).

The typical upstream and downstream water-level records at the Krian barrage show that the barrage has been operated satisfactorily from a hydrological viewpoint. Figure 4(a) depicts the situation during the flood season when the five barrage gates are opened to discharge floodwaters. The operation of the barrage during the flood season should not be of concern with respect to its effect on aquatic life as there is a flow-through condition. Figure 4(b), however, shows typical water levels at the barrage during the dry season when the barrage gates are generally closed to maintain upstream water levels above 0.6 m RL. The barrage operation features observed on 13–14 May 1983 suggest that: first, the daily water-level fluctuations of the barrage are 0.6–2.2 m; and, second, the daily drawdown rate is 0.085–0.375 m/day. It is clear that the operational patterns seem satisfactory and desirable from the viewpoint of requirements for maximizing fish production upstream and downstream of the barrage. This is because the barrage gates generally are opened twice a day (in conjunction with tides). This allows diel movement of fish (Yap and Furtado 1980). However, it should be noted that there may be exceptionally dry periods in certain years and that during these periods the barrage gates may need to be closed almost all the time. It is during these condition that fish production in the river may be affected.

Field observations indicate that the area downstream of the Krian barrage appears to support less angling (5 boats/day) than upstream (30 boats/day). However, compatible fishery records both downstream and upstream of the barrage, corresponding to records for water levels are not available. The lack of satisfactory time-series catch data negates further analysis and conclusions on the possible effects of the magnitude and duration of the drawdown on fish-catch fluctuations and exploitable stocks (Bernacsek 1984).

Conclusions and Recommendations

The cause of decreased fish resources due to the presence of the Krian barrage is thought to be linked with siltation and the barrage operation (MOA 1988). The impact of barrage development on fish stocks could be indirectly due to its impact on water quality, sedimentation, hydrology, and tidal regimes. Its direct impact may be due to declines in biological production processes, a decrease in ichthyoproductivity in saline conditions, nutrient deficiency, the obstruction of fish migratory paths, stress and mass mortalities associated with abrupt downstream discharge,


Open 5
* Close
Open 5
Close
Open
Open 5
Open 1
Open 5
Open 1
Open 5
1.2
1.0
0.8
0.6
0.4
0.2
0
-0.2
Stage above LSD (m)
Upstream barrage
Downstream barrage
* No. of gates opened
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
13 Sep 1983
14 Sep 1983
Time (h)

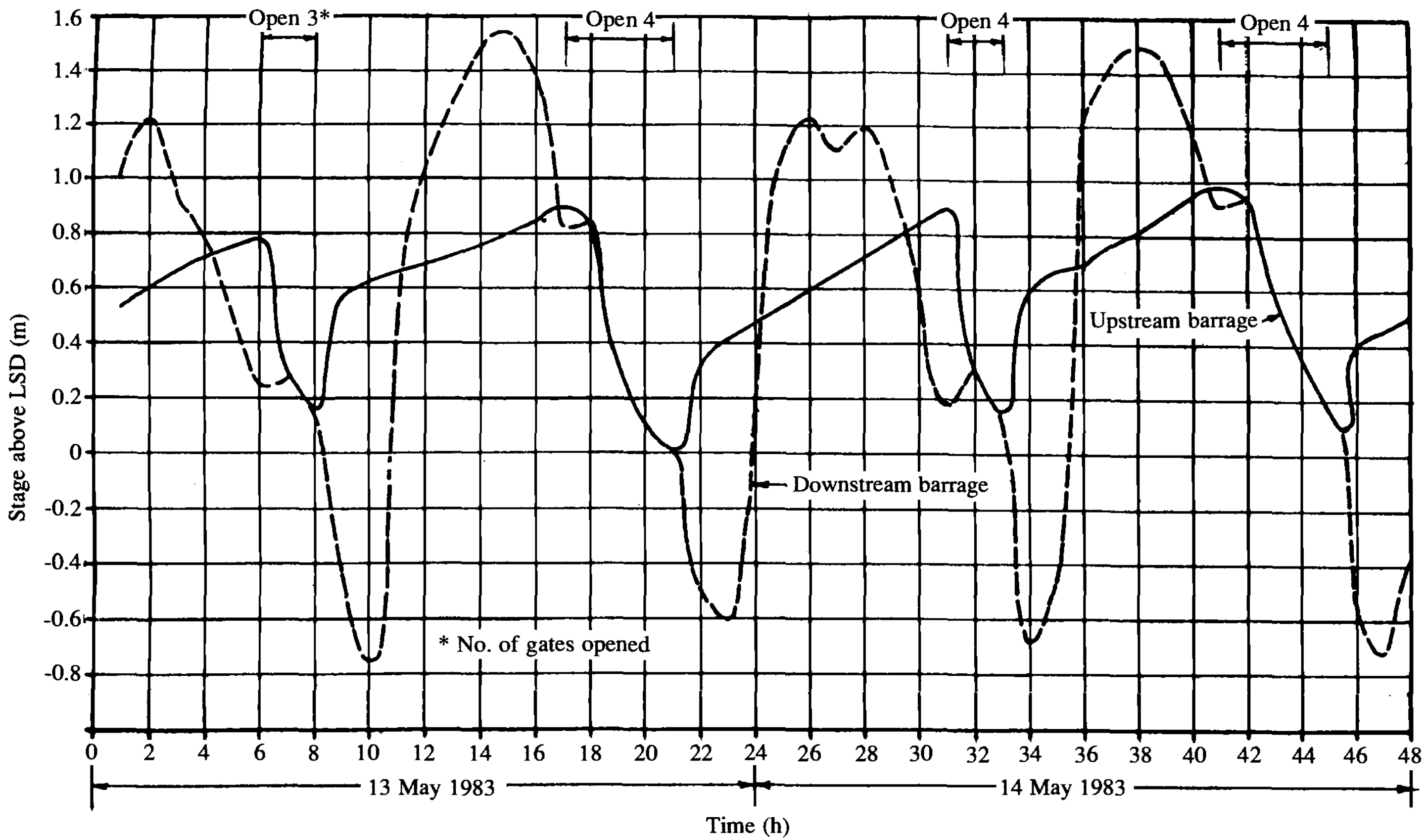


Fig. 4. Water levels of the Krian barrage during the flood season (a) and during the dry season (b).

overfishing, and, possibly, drawdown effects. These ecological problems must be recognized and rectified to maximize the fishery component of the tidal barrage.

As a prerequisite, tidal-barrage design engineers and barrage operators must be fully aware of the hydrological requirements for increasing fish production in upstream and downstream environments of tidal barrages. The Krian barrage survey indicates that the following barrage design and operational features are desirable. Outlet gates for water discharge downstream of the barrage should be designed to discharge the epilimnion layer of the water mass. Alternatives such as a spillway or a diversion canal to maintain flow-through conditions downstream of the barrage should be costed out. Overflows from spillways and flap-gates discharge warm, oxygenated, plankton-rich epilimnion water, and, as was observed at the spillway of Bukit Merah reservoir, can support a sizable fishery (Yap 1982). For existing barrages (e.g., Krian barrage) with a design in favour of discharge of the hypolimnion layer of the stagnant water mass, improved operational procedures (with gates opening twice a day in conjunction with the tide) should be strictly adhered to on a daily basis. During dry periods, even a limited discharge of the hypolimnion should be permitted to decrease the residence time of the stagnant water mass. Changes in the magnitude of downstream discharge should not be abrupt and stressful.

Unlike inland reservoir or upstream riverine dams, the whole Krian barrage and estuary is affected by the semidiurnal tide of the Malacca Straits. The observed correlations between the tides and some of the parameters (*E. coli* count and suspended solids) show that an assessment of the barrage impact on the fisheries ecology cannot be done without consideration of tidal influences. The oscillatory movement of the water caused by tidal movement prevents efficient flushing of suspended solids into the sea, which interferes with self-purification. An additional complication at the tidal barrage is the use of the estuary as a waste-disposal facility.

Barrage operational procedures should be established to maximize the interchange of water to disperse nutrients, sediments, and pollutants, and to reoxygenate the water. A more successful approach to water-quality control at the tidal barrage and affected estuary would be to prevent water pollution upstream of the barrage. This calls for strict enforcement of regulations concerning the discharge of industrial and domestic effluents.

Acknowledgments

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Appendix — List of fish species of the Krian River.

Family	Scientific name	Vernacular name	Common name
Freshwater ecosystem			
Anabantidae	*Osphronemus goramy*	Ikan (I.) Kalui	Giant gouramy
	Trichogaster pectoralis	I. sepat siam	Snake-skin gouramy
	Anabas testudineus	I. puyu/I. betok	Climbing perch
Bagridae	*Mystus vittatus*	I. baung	River catfish
	Mystus gulio	I. baung	River catfish
Clariidae	*Clarias batrachus*	I. keli	Catfish
Cyprinidae	*Labiobarbus festiva*	I. pucuk pisang	
	Puntius gonionotus	I. lampam jawa	Indonesian carp
	Puntius schwanenfeldii	I. lampam sungai	Tin-foil barb
	Osteochilus hasselti	I. terubul	Hassell's bony-lipped barb
Mastacembelidae	*Mastacembelus armatus*	I. tilan	Spiny eel
Ophicephalidae	*Ophicephalus striatus*	I. haruan	Snake-head
Osteoglossidae	*Scleropages formosus*	I. kelisa	Dragon fish
Siluridae	*Ompok bimaculatus*	I. tapah bemban/Lais	

(continued)

Appendix continued.

Family	Scientific name	Vernacular name	Common name
Freshwater and saltwater interface ecosystem			
Palaemonidae	*Macrobrachium rosenbergii*	Udang gala	Giant freshwater prawn
Ambassidae/Percidae	*Ambassis gymnocephala*		
	Ambassis nalua		
	Ambassis commersonni		
Ariidae/Tachysuridae	*Tachysurus caelatus*		
	Tachysurus sagor		
Belonidae	*Strongylura strongylura*		
	Xenentodon cancila		
Callionymidae	*Callionymus melanopterus*		
Centropomidae/Percidae/Latidae	*Lates calcarifer*	I. siakap	Sea perch (sea bass)
Chandidae	*Chanda thomassi*	I. seriding	
	Chanda ranga		
Clupeidae	*Ilisha elongata*		Gizzard shad
	Hilsa toli		
	Anodontostoma chacunda	I. kebasi/Selangat	
Engraulidae	*Setipinna breviceps*		

Gobiidae	*Periophthalmodon schlosseri*	I. tembakal	Mudskipper
Megalopidae	*Megalops cyprinoides*	I. bulan-bulan	Ox-eyed herring Indo-Pacific tarpon
Syngnathidae	*Doryichthys martensii*	I. jolong-jolong	Pipe fish
Tetraodontidae	*Tetraodon* spp	I. buntal	Freshwater puffer fish
Toxotidae	*Toxotes jaculatus*		
Coastal and marine ecosystem			
Carangidae	*Atropus atropus*	I. rambal	Kuweh trevally
	Caranx malabaricus	I. pelata	Yellowtail scad
	Caranx sexfasciatus	I. pulas keladi/Keropoh	Great trevally
	Chorinemus lysan	I. talang	Queenfish
	Decapterus russelli	I. selayang	Round scad
	Selar boops	I. selar kuning jantan	Ox-eyed scad
	Selaroides leptolepis	I. selar kuning	Yellow-banded trevally
Chirocentridae[a]	*Chirocentrus dorab*	I. parang-parang	Wolf herring
Lutianidae	*Lutianus johnii*	I. jenahak	Moses perch
	Lutianus russelli	I. tanda	Russell's snapper
Mugillidae[a]	*Liza subviridis*	I. belanak	Mullet

(continued)

Appendix concluded.

Family	Scientific name	Vernacular name	Common name
Nemipteridae	*Nemipterus japonicus*	I. kerisi	Threadfin bream
Plotosidae[a]	*Plotosus anguillaris*	I. semilang karang	Catfish eel
	Plotosus canius	I. semilang	Catfish eel
Polynemidae[a]	*Elutheronema tetradactylum*	I. kurau/Senangin	Threadfin
Pomadasyidae[a]	*Pomadasus haste*	I. gerut-gerut	Silver grunter
Scomberomoridae	*Scomberomorus guttatus*	I. tenggiri papan	Spotted Spanish makerel
Scombridae	*Rastrelliger kanagurta*	I. kembong	Indian mackerel
Sciaenidae	*Johnius sina*	I. gelama	Drab jewfish
Serranidae	*Epinephelus boenack*	I. kerapu	Coral cod
	Epinephelus sexfasciatus	I. kerapu	Coral cod
Sillaginidae[a]	*Sillago sihama*	I. puntung damar	Silver whiting
Stromateidae	*Pampus* sp.	I. bawal selatan	Small promfret
	Parastromateus niger	I. bawal hitam	Black promfret
	Psenes indicus	I. jepun	Pomfret
Sphyraenidae	*Sphyraena obtusata*	I. kacang kacang	Blunt-jawed seapike
Synodontidae	*Saurida tumbil*	I. mengkerong	Lizardfish

Trichiluridae[a]	*Trichiurus haumela*	I. timah	Ribbonfish
Crustacea — Penaeidae	*Penaeus monodon*	Udang harimau	Tiger prawn
	Penaeus merguiensis	Udang laut kaki Merah	Banana prawn
Mollusca — Arcidae			
	Loligo edulis	Sotong	Squid
	Sepia spp	Sotong katak	Cuttlefish
	Anadara granosa	Kerang	Red-blood cockle

Sources : Yap, personal observation January and February 1989; DOF–Krian, 18 January 1989; Yap 1978–87 (unpublished); Mohsin and Ambak 1983; Zakaria 1983; Jothy et al. 1983.

[a] Also found in mangrove and inshore waters.

Postimpoundment Studies on Aquatic Ecology and Fisheries in Bhumibol and Sirikit Reservoirs, Thailand

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Aquatic ecology and fisheries studies were conducted in two reservoirs, Bhumibol and Sirikit, 23 and 14 years after impoundment, respectively. Plankton populations varied between wet and dry seasons. There were 34 fish species belonging to 15 families in Bhumibol and 31 fish species belonging to 18 families in Sirikit. Over 1 000 t of fish were caught per year from each reservoir. Some aquaculture, such as cage culture, is practiced in the reservoirs. The Department of Fisheries stocks the reservoirs and has implemented a management program to enhance fish production.

After construction of the Bhumibol dam in 1963 and the Sirikit dam in 1972, the impoundments have been used in many ways. Fish production and related fishery activities have expanded and are considered economically important. However, few ecological studies have been done, especially so many years after impoundment. To evaluate the overall benefits from these two dams, and to collect data for further development planning, a postimpoundment environmental study was conducted. The results can be used as a guideline for the environmental and economic evaluation of various development projects in Thailand and elsewhere in the tropics.

The main objectives of the study were two-fold:

- To investigate existing conditions of fish resources in the reservoirs, with emphasis on water quality characteristics related to aquatic life, distribution and abundance of plankton, benthic organisms, aquatic macrophytes, and fish populations; and
- To investigate fishery activities in the reservoirs, including socioeconomic conditions.

Materials and Methods

Water samples were collected at each station at three depths: 1 m below the surface; at mid-depth; and a few metres above the bottom. The samples were stored in polyethylene bottles and sent to the laboratory for chemical analysis. The analytical methods were those suggested in the Standard Methods for Water and Wastewater Examination (APHA 1985).

Plankton samples were collected by using a 70-µm mesh net towed vertically and horizontally. Samples were preserved in 5% formalin. Benthic samples were collected using an Ekman dredge. Sediments were screened through sieves of various mesh sizes and organisms were preserved in 5% formalin.

The abundance of aquatic plants in the reservoirs was investigated using a rectangular (1 × 1 m) frame. The species and their distribution were also recorded. Samples were preserved for taxonomic study.

Seine nets and a poison method were used to collect fish samples. The fishery potential and fishing activities in the reservoirs were determined in terms of number of people fishing, type of fishing gear, total catch and landing statistics, income from fishing, and other socioeconomic data. Field observations and questionnaires were used. Other fisheries activities, such as fish culture, were investigated in the reservoirs and downstream.

Field investigations for fisheries and ecological studies in each reservoir were conducted in April and November 1985, which represented the dry and rainy periods, respectively. Field surveys on fisheries activities, landing statistics, and socioeconomic conditions were conducted every 2 months from April 1985 to March 1986.

Results

Morphometric and hydrobiological features of Bhumibol and Sirikit reservoirs are presented in Table 1.

Table 1. Morphometric and hydrobiological features of Bhumibol and Sirikit reservoirs.

	Bhumibol	Sirikit
Location	Ping River	Nan River
Area (km^2)	318	260
Elevation (m above MSL)	260	166
Volume (10^6 m^3)	13 462	10 500
Year of inpoundment	1 963	1 972
pH	7.2–7.8	6.5–7.4
Alkalinity (mg/L)	54–126	60–84
Dissolved oxygen (mg/L)	5.6–7.7	7.1–7.9
Transparency (m)	0.3–0.4	0.3–1.8
Temperature (°C)	30.0–32.5	28.5–31.5
Phytoplankton species	25	23
Zooplankton species	31	31
Benthos species	3	2
Fish species	34	31

Note: MSL = mean sea level.

Bhumibol Reservoir

In general, water quality in Bhumibol reservoir was suitable for aquatic life. The pH was 7.2–7.8 and dissolved oxygen content 5.6–7.7 mg/L. In total, 25 species of phytoplankton and 31 species of zooplankton were recorded. There were changes in plankton species composition and abundance during the dry and wet seasons. Dinoflagellates (*Ceratium* spp) were the dominant species in the dry season; the rotifer (*Brachionus* sp.) was dominant in the wet season. The most common benthic species were gastropods, oligochaetes, and insect larvae. Aquatic macrophytes included water hyacinths and *Mimosa pigra*, but they were found in low abundance.

Thirty-four species of fish, belonging to 15 families of carps (Family Cyprinidae), were dominant. The most common species were: *Puntioplites proctozysron*, *Oreochromis niloticus*, *Puntius gonionotus*, *P. leiacanthus*, *Cyclocheilichthys armatus*, *Cirrhinus jullieni*, *Hampala macrolepidota*, *Channa striatus*, and *Rasbora* spp. The estimated standing crop of fish in the study area was 305.6 kg/ha in the dry season and 239.4 kg/ha in the wet season.

The species composition of fish during the wet and dry seasons was different. Carps were the dominant group, accounting for 52% (by weight), whereas, catfish, murrels, and miscellaneous groups accounted for 4, 5, and 39%, respectively. The fish composition ratio observed in this study is in the range reported as typical of reservoirs after 5 years of impoundment (Sidthimunka 1972).

Fishing at the Bhumibol reservoir started after impoundment. The main activity in the reservoir is capture fisheries; however, some cage culture has just started. The first group to fish were farmers and local people who had lost their land during inundation. During the first few years, catches per person were high. However, the number of people fishing has gradually increased because of the high incomes available from fishing and the fact that there are no restrictions to entry to the reservoir. At present, about 475 people fish on the reservoir each day and, of these, about 85% operate in the upper section, especially at Doi Tao.

Fishing in the reservoir is permitted throughout the year. Commercial catches have been recorded since the start, but records are irregular. Previously, there were at least three landing sites: at the dam, Wang Luang district, and Doi Tao district. At present, more than 90% of the fish are landed at Doi Tao; the remainder are landed at the dam. Commercial catches fluctuate from year to year. Catches of over 1 000 t/year were recorded in 1965 and 1973 (Table 2). Seasonal fluctuation is usually greatest during the rainy season (June to November).

The dominant species are *Oreochromis niloticus*, *Puntioplites proctozysron*, *Cirrhinus jullieni*, *Puntius gonionotus*, and *Morulius chrysophekadion*. Cyprinids dominate the catch and contribute over 56.8% of the annual fish landings. This is about the same as the fish composition observed using a poisoning method (51.6%).

Comparing the average commercial yield per unit area with the observed standing crop, it was found that the average commercial catch is lower than the average standing crop figures in this study. It can be hypothesized that fishing pressure in the Bhumibol reservoir is below the maximum sustainable level (using an average standing crop of 48.1 kg/ha). In addition, the number of people fishing in the reservoir (1.5 people/km^2) is lower than that in other reservoirs in Thailand, such as Ubolratana, which can be as high as 14 people/km^2 (Bhukaswan 1985).

Table 2. The commercial fish catch from Bhumibol and Sirikit reservoirs.

Year	Fish catch (t)	
	Bhumibol	Sirikit
1964	545	—
1965	1 089	—
1966	753	—
1967	676	—
1968	785	—
1969	673	—
1970	806	—
1971	889	—
1972	—	784
1973	1 106	1 032
1974	952	506
1975	—	1 132
1976	913	599
1977	—	1 343
1979	853	695
1980	502	1 053
1981	434	1 019
1982	673	1 117
1983	698	1 071
1984	760	874
1985	772	712

The socioeconomic study indicated that most of the people fishing in Bhumibol were previously engaged in farming and changed to fishing. However, some of them are not full-time, but engage in fishing after the rice paddy harvest. Those who live near the reservoir, or in floating houses, rely mainly on fishing. The average fishing family is about four persons, but only one will fish. The main types of fishing gear are gillnet, hook and line, lift nets, and bamboo traps. Gillnets constitute about 80% of all fishing gear. Mesh size varies — 8 cm is the most popular, followed by 3 cm and 7 cm.

Most people who fish own a boat. The ratio of rowboats to motorboats is about 2:1. Capital investment in fishery in the Bhumibol reservoir is not high. However, there are still some people who do not have adequate cash to invest. These people sell their catch to their creditors, sometimes below the market price.

The daily catch in the reservoir averages 4.5 kg/person. Some portion of this is used for household consumption (about 0.7 kg/family); the remainder is sold. The average income from fishing in the Bhumibol reservoir is about 39 THB/day (1 USD = 20 THB).

Distribution of the catch from the Bhumibol reservoir starts early in the morning. Fishmongers buy the fish nearby and deliver them by motorboat to the landing site. The fish are then sold to wholesalers, who buy fresh fish for resale at retail markets, or to fish processors who buy fish for fermenting, salting, or smoking.

The problems and constraints to fishing in the Bhumibol reservoir include:

depletion of fishery resources, resulting in low catch, especially of economically important species; strong winds in unprotected areas during part of the year; and theft of fishing gear.

At present, there is no commercial aquaculture activity in Bhumibol. Some fishing households, or floating houses, will have a wooden cage for holding some fish species. The main purpose is to keep some economically important species such as *Osphronemus goramy*, *Oxyeleotris marmorata*, and *Pangasius sutchi* for future consumption.

Fish stocking has been practiced in Bhumibol since impoundment. The objectives of the stocking program are: to increase fish productivity by maximizing the utilization of natural food resources, which are not used by the indigenous fish species, and to control aquatic vegetation. Stocked species include *O. niloticus*, *Trichogaster pectoralis*, *Pangasius sutchi*, *Cyprinus carpio*, and Chinese carps. Several stocked species are indigenous species that lived in the rivers before impoundment. It is difficult to evaluate the benefit of the stocking program; however, some introduced species, such as *O. niloticus*, have dominated the commercial catch in the reservoir over the past few years.

Sirikit Reservoir

Water quality in Sirikit reservoir is favourable; pH is 6.5–7.4 and dissolved oxygen 7.1–7.9 mg/L. There are 23 species of phytoplankton and 31 species of zooplankton. The most abundant species during the dry period is a dinoflagellate (*Ceratium* sp.); in the wet period, a diatom (*Melosira* sp.) is most abundant. Plankton populations in Sirikit reservoir are lower than in Bhumibol, indicating a lower primary productivity. Only two species of benthic organisms were observed in Sirikit: a bivalve mollusc (*Limnoperna* sp.) and chironomids (*Chironomus* sp.). Some aquatic macrophytes, including water hyacinth, were observed but they are not abundant.

There were 31 species of fishes belonging to 18 families. Carps (Family Cyprinidae) were dominant. The most common species were *Ambassis siamensis*, *Toxotes chatareus*, *Pristolepis fasciatus*, and *Osphronemus goramy*. The numbers of fish species observed were the same during both seasons.

The estimated standing crop of fish in Sirikit reservoir was 33.3–123.1 kg/ha, with an average of 83.7 kg/ha. The estimate in this study is similar to the values of 63.7–98.7 kg/ha observed between 1973 and 1981.

The species composition of fish caught in the study area varied among sampling stations. The average percentages by weight of carps, catfish, murrels, and miscellaneous groups were 21, 12, 1, and 66%, respectively. The fish species composition observed in this study was different from previous records.

Inland fisheries by local people in the Sirikit reservoir started after inundation in 1972. During the first few years, there were only 77 fishing families inhabiting the reservoir, but now there are about 550 families. Most fishing families construct floating houses that can be relocated to suitable areas for fishing and for protection against strong winds. In general, these people will fish everyday unless conditions, such as storms or strong winds, make it impossible. There are three landing sites:

- Tambon Tha Rua, Tha Pla district, Uttaradit Province, near a saddle dike where about 80% of the fish are landed;
- the Sirikit dam, where about 10% of the fish are landed; and
- Ban Pak Nai, Na Noi district, Nan Province, where the rest are landed.

The total commercial fish catch from Sirikit has been recorded since 1972 and has not fluctuated very much. The highest catch (1 343 t) was recorded in 1977. From 1980 to 1983, the recorded annual catches were over 1 000 t, but from 1984 to 1985, annual catches decreased (Table 2). The reduction in the yield may be due to the increase in the number of people fishing, which rose from 0.3 people/km^2 in 1972 to 2.1 people/km^2 in 1985.

Corica sp. account for about 30% of the catch (by weight). About 300 light-attraction lift nets for these freshwater sardine-like fish are operated at night. During the new moon, when conditions are calm, more than 1 t of this clupeid is caught each day. This fish is also found abundantly in some other reservoirs such as Ubolratana. *Corica* sp. is fermented, and some people use it to feed carnivorous fish, such as *Channa* sp., that are cultured in cages. The average catch per unit area is 19.4–51.6 kg/ha, which is lower than the standing crop estimated in this study (83.7 kg/ha).

The socioeconomic study in Sirikit indicated that most of the people were engaged in farming but changed to fishing. Some still maintain both occupations. The average fishing household is about 4.7 persons, but only one person fishes. The main types of fishing gear are gill nets, lift nets, and hook and line. Gill nets are the most popular type (70%). Lift nets or light-attraction lift nets for *Corica* sp. are also popular. The common mesh sizes of the gill nets are 7 and 10 cm. Most people own a rowboat or motorboat and use it for fishing beside the floating house. The ratio of rowboats to motorboats is about 1.2:1.

The average daily catch in Sirikit is about 4.8 kg/person. About 0.6 kg is used for household consumption; the remainder is sold to fishmongers or wholesalers. The average daily income from fishing is about 60 THB.

There is some aquaculture activity in Sirikit, especially at Tha Pla and at Ban Na Noi in the upper section of the reservoir in Nan Province. Snakehead (*Channa micropeltes*), *Oreochromis niloticus*, and *Oxyeleotris marmorata* are cultured. Cage culture started when large numbers of small, high-priced fish were kept for household consumption. Only snakehead fingerlings had to be bought from elsewhere for stocking cages. Giant snakehead culture started a few years ago when it was recognized that plenty of natural food, especially *Corica* sp., was available in the reservoir at a very low price (about 3 THB/kg). The size of hardwood cage used for giant snakehead varies, but is usually about 3 × 6 × 1.5 m in depth. About 3 000 5-cm fingerlings are stocked in each cage. Fish are fed *Corica* sp. until a marketable size (about 1 kg) is reached, usually in about 6–7 months, and are sold at 20 THB/kg. Fish production per cage is about 2.5 to 3 t.

Several species of fishes have been stocked in Sirikit by the Department of Fisheries since 1973. Some are local species, such as *Probabus jullieni* and *Puntius gonionotus*. The introduced species include *Oreochromis niloticus*, *Labeo rohita*, and Chinese carps. The main objectives of fish stocking are to increase production and to utilize natural foods more efficiently. Some introduced species, especially *O.*

niloticus and *L. rohita*, are caught daily in large quantities. *Pangasius gigas* (giant catfish) was introduced into the reservoir in 1984. Some have been recaptured but no data are available.

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Effect of Impoundment on the Indigenous Fish Population in Indrasarobar Reservoir, Nepal[1]

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Changes in the fish species composition resulting from the damming of the Kulekhani River in Makwanpur, Nepal, are discussed. There has been a decline in bottom-feeding insectivores, especially of the families Cobitidae, Channidae, Sisoridae, and Cyprinidae. In particular, Garra lamta *and* Puntius *spp have disappeared and* Schizothorax richardsoni *has declined sharply. Native omnivorous species such as* Accrossocheilus hexagonolepis *and* Puntius chilinoides *have become dominant. The growth of planktivorous carps,* Hypophthalmichthys molitrix *and* Aristichthys nobilis, *is similar to growth in other areas of Nepal. The changes in the fish population in Indrasarobar and other artificial Indian lakes are briefly compared.*

When rivers are impounded, qualitative and quantitative changes in limnological conditions are expected (Lewis 1974). The aquatic environment provided by the semistatic waters of the lake differs markedly from that which prevailed before inundation. The transition from riverine to lacustrine conditions probably has profound effects on the aquatic conditions and fauna of the area. This paper provides information on the effect of the Indrasarobar reservoir dam on the population of native fish species.

Study Area

Indrasarobar reservoir at Kulekhani, Nepal, has recently been formed by damming the Kulekhani River. It is part of a long-term hydroelectric power development program in Nepal. Construction was completed in 1981 and the reservoir was subsequently flooded. It is situated in the mid-hill region of Nepal and has a catchment area of 126 km^2. At full water capacity, Indrasarobar is about 7 km long, 380 m wide, has a maximum depth of 105 m, and a volume of 85.3×10^6 m^3 (Table 1). The valley in which the reservoir is located has steep sides, and the depth of the reservoir varies greatly. For example, in June 1986, the water was 78 m deep and the volume was reduced to 39×10^6 m^3 with a surface area of only 130 ha.

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[1]Not presented in person at the workshop.

Table 1. Characteristics of Indrasarobar reservoir.

Months 1986/87	Maximum depth (m)	Surface area (ha)	Water volume (10^6 m^3)	Mean river discharge (m^3/s)
Jul	94	186	63.5	11.0
Aug	96	193	65.0	10.4
Sep	103	222	80.5	8.1
Oct	105	226	85.3	4.2
Nov	105	226	85.3	2.4
Dec	105	226	85.3	1.7
Jan	103	222	80.2	1.3
Feb	98	200	67.5	1.2
Mar	93	182	60.6	1.2
Apr	86	158	47.8	1.2
May	82	144	44.0	1.2
Jun	78	130	39.0	4.8

The reservoir is normally at full capacity during the winter months (November and December). From December to May, the discharge of the Kulekhani River is minimal, about 1.2 m^3/s. The rainy season normally begins in June and lasts until October. The river discharge increases almost 10-fold to a peak of 10–11 m^3/s in July and August. Indrasarobar is almost isothermal to a depth of 60 m during the winter months of November–February (Fig. 1). It then undergoes progressive stratification during the warm months of March to June, when the water level is falling. Although the reservoir continues to warm during July and August, its temperature stratification is partially broken down by the July to October rains. By November, the reservoir again becomes isothermal down to 60 m. During the short period of strong stratification, a thermocline was found between 8 and 12 m.

Dissolved oxygen concentration in the top 3 m of the reservoir remained above 6 mg/L throughout most of the year. Only in June and July did it remain at or above 4 mg/L (Fig. 2). In contrast, below 5 m depth, oxygen concentration declined to less than 3 mg/L from May to October. When the water temperatures were greater than 20°C below 20 m, oxygen concentrations in the range 1–2 mg/L were found from May to October. The total bicarbonate alkalinity of the reservoir rose from 62 mg/L in December to 75 mg/L in June, then dropped during the rainy season to 36 mg/L by November. The pH in the top 2 m varied from 7.8 during December–February to 10 during May–August. The annual average conductivity of the top 10 m of the reservoir was 87 S/cm^2.

Environmental Changes

The Kulekhani River is one of the tributaries of the Bagmati River system in central Nepal. The stretch of the river now occupied by Indrasarobar reservoir was a narrow channel with agricultural terraces on both banks. It was a relatively fast-flowing hill stream with a few shallow pools. Three spring-fed streams join this river within this stretch. A reduction in the velocity of the current to an almost imperceptible level and the elimination of all rapids and stretches of broken water constitutes a change in environmental conditions that must inevitably affect the fish population.

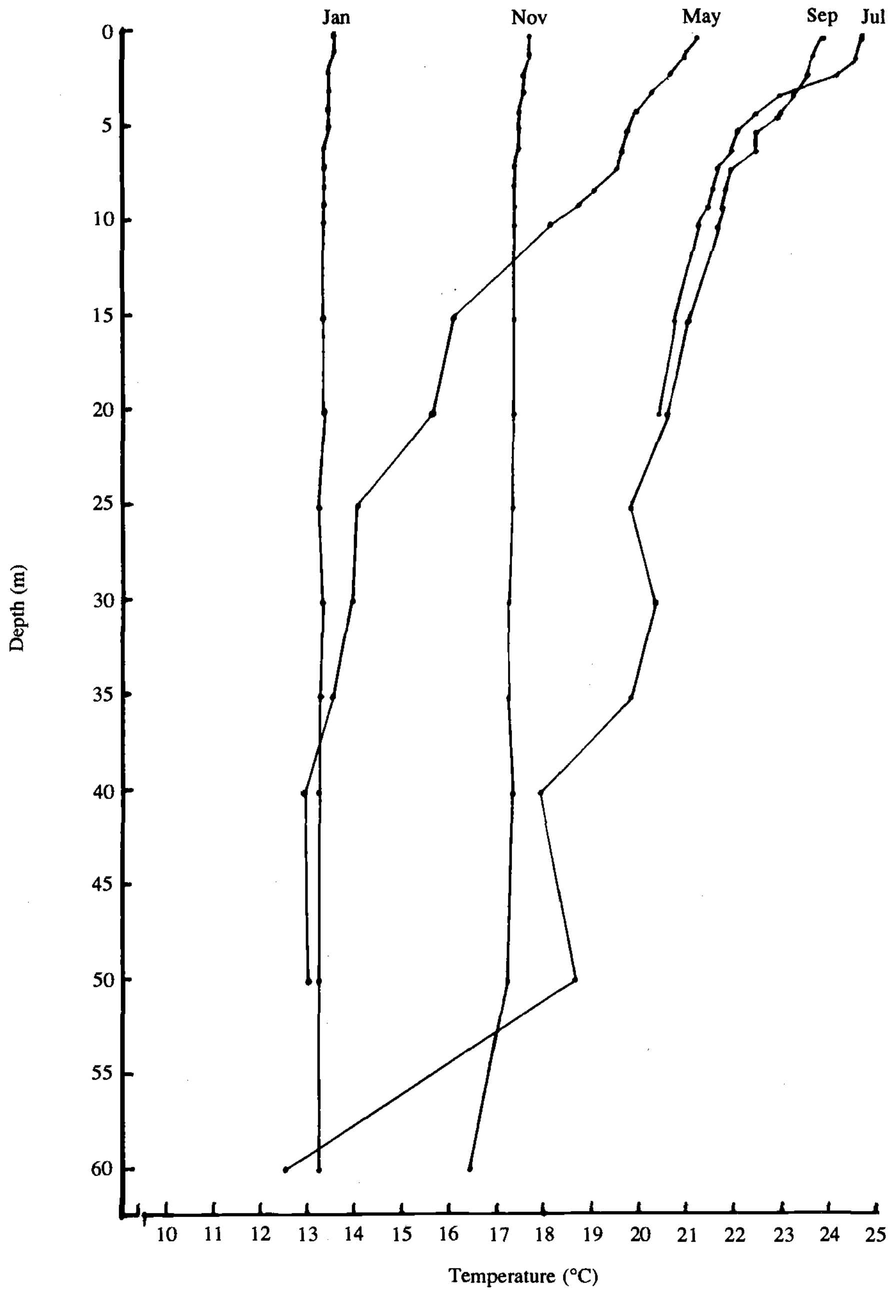

Fig. 1. Vertical temperature of Indrasarobar in 1986–1987.

Species that are morphologically, physiologically, or ecologically adapted to a fluviatile regime would probably find the conditions in the reservoir untenable, whereas, species that, in a riverine system, were restricted to pools would adapt to

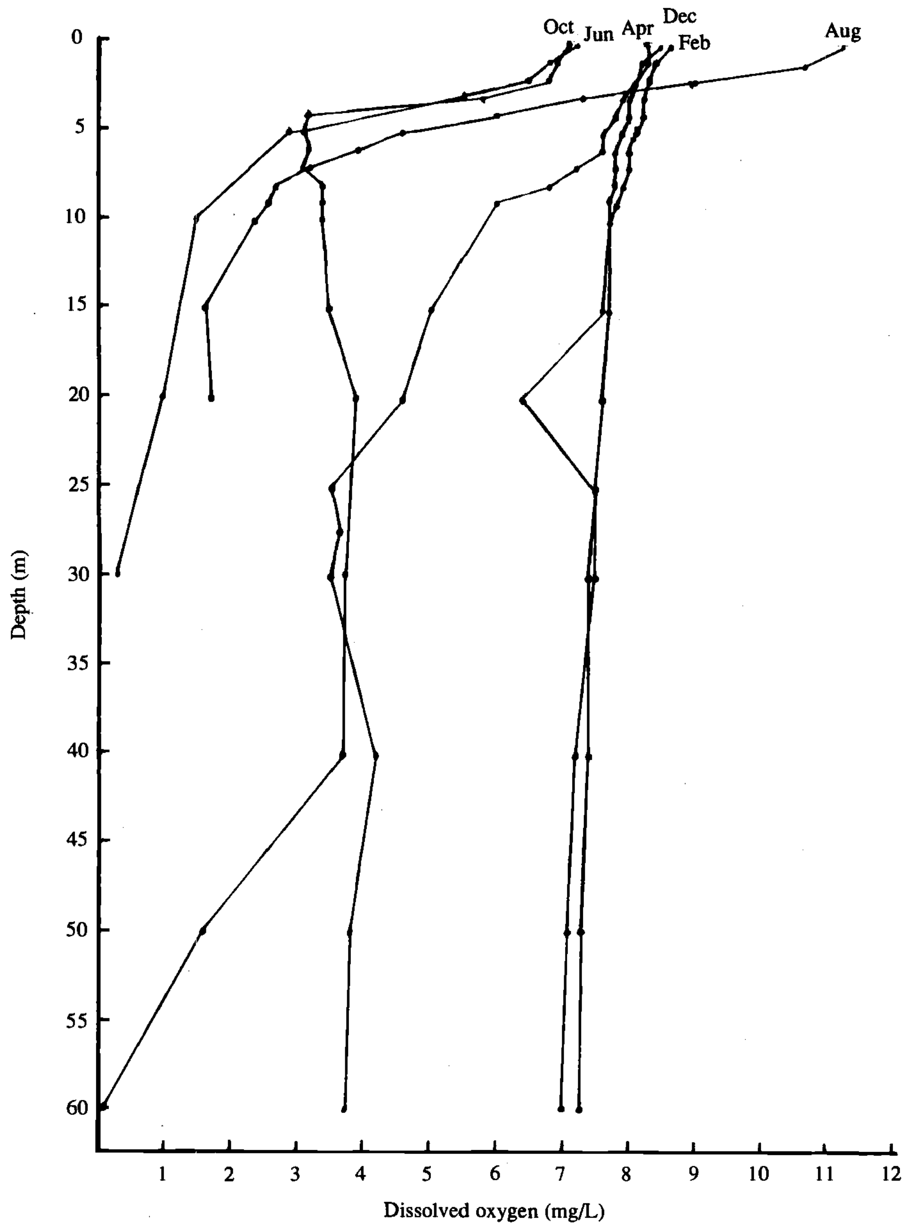

Fig. 2. Dissolved oxygen profile of Indrasarobar in 1986/87.

the new conditions. Changes in the composition and abundance of both planktonic and benthic communities would also affect the food supply of many species of fish. This factor would further influence the species composition of the fish population.

It was, therefore, possible to predict, before the formation of the Indrasarobar reservoir, that the fish population would become dominated by pool dwellers and species that are not selective in their choice of habitat. Likewise, those species that for various reasons require a riverine environment would decrease in number or completely disappear.

Population Changes

The first documented survey of the fish species composition of the stretch of the Kulekhani River now occupied by the reservoir was conducted in 1980 (Shrestha et al. n.d.). The Cyprinidae were the most abundant family. *Garra lamta, Accrossocheilus hexagonolepis, Puntius chilinoides, Schizothorax richardsoni, Puntius ticto ticto,* and *Puntius* spp were found. The Cobitidae were represented by *Noemacheilus* spp, and the Channidae by *Channa gachua*. The family Sisoridae was represented by two species, *Glyptosternum* sp. and *Coraglanis* sp.

A survey of fish fauna upstream of the reservoir in 1984/85 revealed that the Cyprinidae were the most abundant family (no figures given), followed in order of importance by the Sisoridae, Cobitidae, and Channidae (Pradhan 1986a). A comprehensive study of the composition of the fish population of Indrasarobar reservoir was made in 1985–1988 (Pradhan 1986b, 1987, 1988; Rai 1989). Monthly experimental fishing was carried out from seven stations distributed throughout the lake using multipanel gill nets with stretched mesh sizes of 25, 50, 75, and 100 mm. The annual catch per unit effort (CPUE) was 0.12–1.7 g/m^2 per h in 1985/86 and 0.12–1.1 g/m^2 per h in 1986/87 (Pradhan and Swar 1988). The percentage composition by weight and number of the major species from 1985 to 1987/88 is illustrated in Fig. 3. The Cyprinidae is the only family that remains in the reservoir. The other three families were eliminated from the reservoir, except that *Channa gachua* was caught in the 1985/86 samples.

Accrossocheilus hexagonolepis (commonly known as *asala*) was the dominant species in the reservoir throughout the study period. It comprised 62% (1986/87) to 80% (1988/89) by weight, and 39% (1986/87) to 71% (1988/89) by number. *Puntius chilinoides* was the second dominant fish. It comprised 14% (1988/89) to 28% (1986/87) by weight, and 27% (1988/89) to 57% (1986/87) by number. *Asala* was the most abundant species in the preimpounded river. In the reservoir, it formed a very small component of gill-net catches, never more than 2% by weight and 6% by number. However, *asala* is still abundant in the upstream area above the reservoir.

Three species, *Hypophthalmichthys molitrix* (silver carp), *Aristichthys nobilis* (bighead carp), and *Tor tor* (mahseer), which were not native to the Kulekhani River appeared in the catches in 1986/87. They formed a considerable percentage of the catches in 1987/88 and 1988/89. These species were not deliberately introduced, but escaped from cages.

These planktivorous Chinese carps (silver and bighead) are showing encouraging rates of growth, both in the open water and in floating cages. Changes in fish species composition are shown in Table 2.

Discussion

The transformation of a river into a lake can affect the indigenous fishes in a variety of ways. Craig and Bodaly (1988) described several important factors and

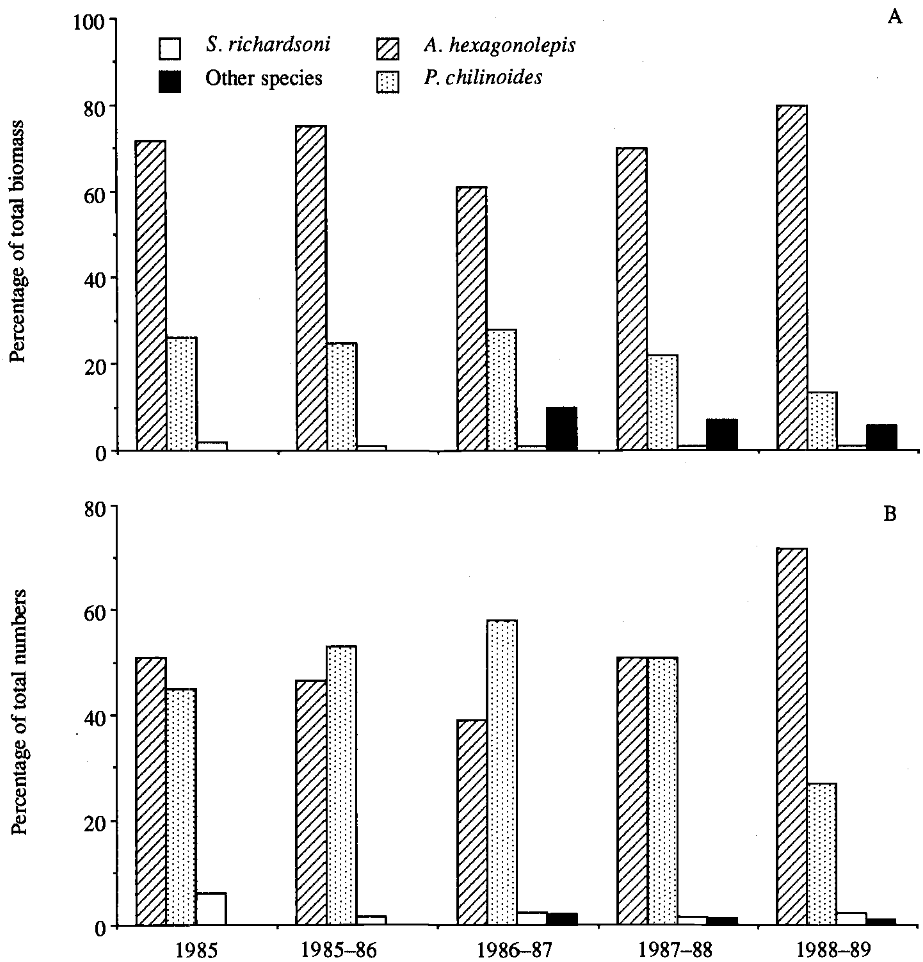

Fig. 3. Percentage composition of the major fish species from 1985 to 1986/87: (A) biomass and (B) numbers.

their influence on the existing fish population. Dams without provision for fish passage can prevent the movement of migratory fish. The whole flow of the Kulekhani River has been diverted to the hydroelectric turbines through a 9-km tunnel and there is no provision for fish movement. This must have created adverse conditions for species that need to migrate for spawning.

Food supplies available to fish populations are profoundly affected by impoundments. An immediate effect of the formation of the Indrasarobar reservoir was an increase in the amount of inorganic and organic fertilizer from the agricultural terraces in the catchment area. The development of abundant populations of phyto- and zooplankton in the newly formed reservoirs provided a rich food supply for a variety of omnivorous and planktivorous species, including katle, karange, and bighead, and silver carps. Silver and bighead carps have exhibited high growth rate in floating cages and in open water in the eutrophic Begnas Lake (Swar and Gurung 1988; Swar and Pradhan 1990). The formation of the reservoir also destroyed many

Table 2. Changes in fish species composition in Indrasarobar.

Introduced	Disappeared	Dwindled	Now dominant
T. tor	*G. lamta*	*S. richardsoni*	*A. hexagonolepis*
A. nobilis	*P. ticto ticto*		*P. chilinoides*
H. molitrix	*Puntius* spp		
	Noemacheilus spp		
	C. gachua		
	Glyptosternum spp		
	Coraglanis spp		

food sources, notably benthic organisms and aquatic insects belonging to the orders Ephemeroptera, Odonata, Plecoptera, Megaloptera, Trichoptera, Lepidoptera, Coleoptera, and Diptera. These insects are still abundant in upstream areas (Pradhan 1986b). This is partially due to siltation, the anoxic bottom, and the pronounced annual drawdown that affects littoral production. The result was the virtual elimination of specialized bottom feeders and insectivores such as *Puntius* spp, *Noemacheilus* spp, *Glyptosternum* spp, *Coraglanis* spp, and *asala*. The bottom dweller, *Channa gachua*, has also vanished, perhaps due to the anoxic bottom condition of the reservoir.

The fish community in the reservoir is strongly influenced by changes in the spawning habitats. The effect of the impoundment of Indrasarobar reservoir on the recruitment of various species is still largely unknown because the breeding cycle and spawning requirements of katle and karange are not known. Considerable numbers of mature katle and karange were caught from the middle of the lake during the breeding seasons of 1986 and 1987. Thus, it seems these species have been able to modify their spawning habits to cope with the conditions prevailing in the reservoir. This is under further investigation.

There have been several studies on tropical African and Indian impoundments, and general fisheries and fish population changes have been described by several workers (Bhattanagar 1967; Petr 1967; Lewis 1974; Motwani and Saigal 1977; Chaudhary 1978; Singit et al. 1988). Sreenivasan (1974) studied the fishery and changes in fish fauna in seven reservoirs in southern India. A direct comparison between Indrasarobar and southern Indian water bodies is not possible. However, the most obvious similarity between the population changes in Indrasarobar and the Indian reservoirs (Stanley, Amaravaty, and Tungabhadra reservoirs) is the disappearance of the *Puntius* spp. There is also evidence of elimination of migratory fish in Syndynulla reservoir. Most of these Indian reservoirs are stocked with fast-growing native fishes. No such attempts have been made in Indrasarobar.

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Barrier Facilities in Chinese Reservoirs

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Barrier facilities in Chinese reservoirs are described. Barriers are used to prevent fish from escaping in large to medium reservoirs. Economic efficiency, survival, and yield of stocked fingerlings is closely related to the type of barrier facilities constructed. In Donzhang reservoir (1 000 ha), Fujian Province, for example, operation of a barrier facility has increased yields from 7.5–15 kg/ha per year (1960–1982) to 150 kg/ha per year (present). This paper deals with the operational scope, structure, and application efficiency of fence, barrier net, and electric fish screens commonly used in Chinese reservoirs. The construction and multiple functions of a large-span barrier in Taipinghu reservoir is discussed.

Reservoir fisheries are an important component of Chinese freshwater fisheries. Barriers are used to prevent fish from escaping from large and medium reservoirs. This practice has shown that economic efficiency, survival, and yield per hectare of stocked fingerlings are not only dependent on fish species, density, predator elimination, fishing technology, and fishery management, but also closely related to the type of barrier. For example, during 1960–1982, about 100 million fingerlings were stocked in Donzhang reservoir (1 000 ha) in Fujian Province, but the total production in those years was about 500 t, or about 7.5–15 kg/ha per year. In 1984, a barrier net was installed in this reservoir. After more than 4 years, the average fish production has now exceeded 150 kg/ha per year (Xu 1985).

Environmental Factors Influencing Fish Escape

Fish escape usually takes place at the outlets or inlets of the reservoir. Factors that cause fish escape are very complicated. The main factors are usually water temperature, flow, and water quality and levels. Moreover, fish escape is also related to food organisms, climate, and illumination.

Each species has an optimal temperature range for growth. When the temperature rises above or drops below the range, fish will swim horizontally and vertically to find a suitable environment; this is known as a "habitat movement." Temperature changes act as signals indicating the time for overwintering, feeding, spawning, and other activities of fish.

Water flow is also an important factor influencing fish behaviour. For example, during the flood season, the water temperature is optimal for spawning and will stimulate brood fish to migrate upstream to the spawning grounds.

Fish will also try to escape if the water quality changes suddenly. During floods, increased turbidity causes silver carp and bighead to move downstream and to try to escape (Li and Xu 1988).

Conditions for Barrier Facilities

Barrier facilities are usually set up near the spillway, culvert, or upstream area of the reservoir. Some basic principles for construction of barrier facilities are:

- When the water flow reaches the designed flow rate, it will have no adverse effects on the overflow of flood water and the safety of hydraulic structures;
- Barrier facilities should be strong, but possess a filtering ability;
- Barrier facilities that are on main transportation channels should be designed with boat-passing devices;
- If conditions permit, barrier facilities should be designed so that they prevent fish from escaping during the flood season, and catch fish during other seasons.

Types and Applications of Barrier Facilities

Two basic barrier facilities are commonly used in Chinese reservoirs: fences and barrier nets. In the past decade, electric fish screens have been used for spillways in small hilly reservoirs, where water flows are comparatively slow.

A fence is classified by the construction and material as bamboo (wooden) fence, bamboo basket, or wire fence (Fig. 1). Fences are used widely in reservoirs in China, and are normally installed at the culvert inlet of medium and small shallow reservoirs. Bamboo fences have the advantages of being simple, being made of readily available materials, and being simple to manage. However, they are sometimes destroyed by the strong water flow during heavy storms.

Nets are an effective fish barrier widely used in Chinese reservoirs. They have been adopted in large and medium reservoirs with various spans and water depths.

Electric screens are usually operated in the spillways of medium and small reservoirs, with a water speed less than 0.7 m/s for adult fish, and less than 0.5 m/s for fingerlings. Electric fields are produced by electrodes in the water, and the fish retreat when they receive a shock. Three types of electric fences are used: alternating current; direct current; pulse current. Electric screens with a single row of electrodes of the alternating current type are commonly used in small reservoirs (Fig. 2).

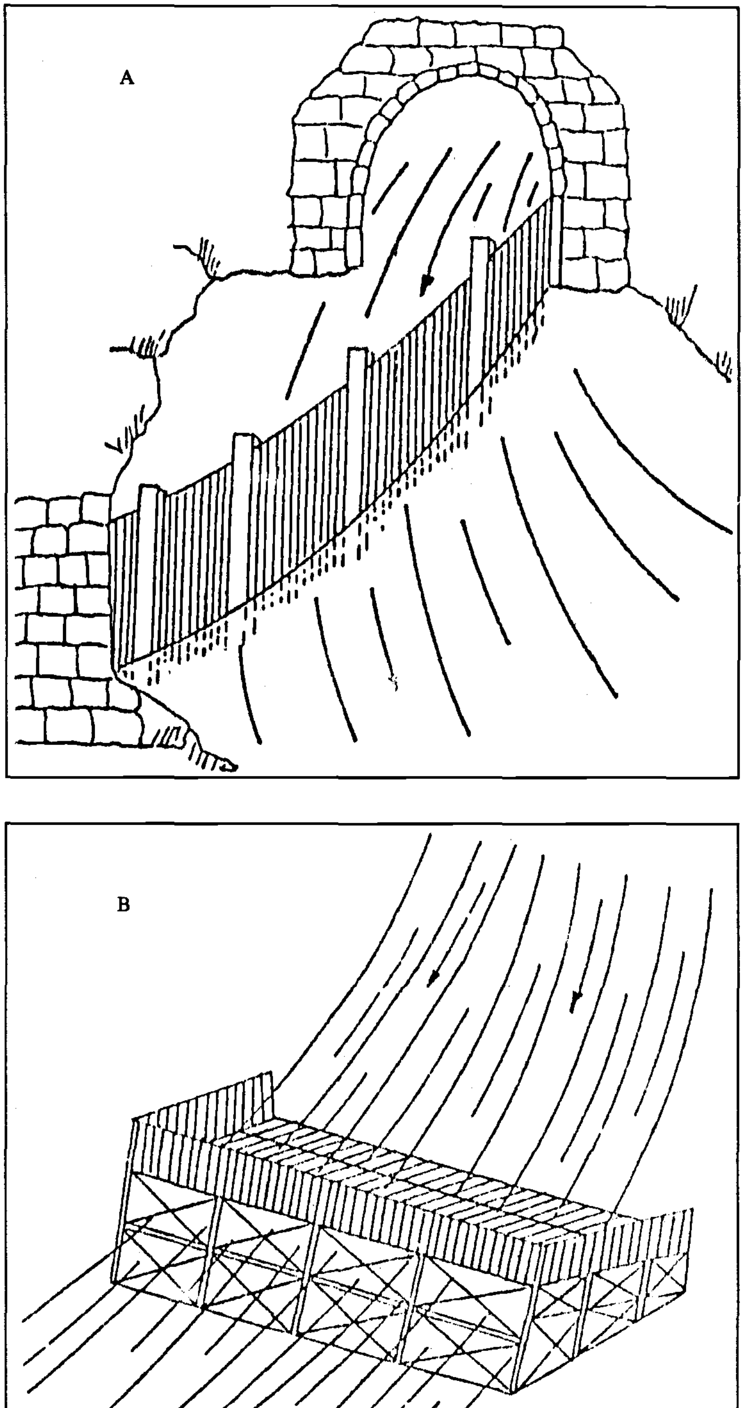

Fig. 1. Types of fences: A. bamboo (wooden) fence; B. wire fence.

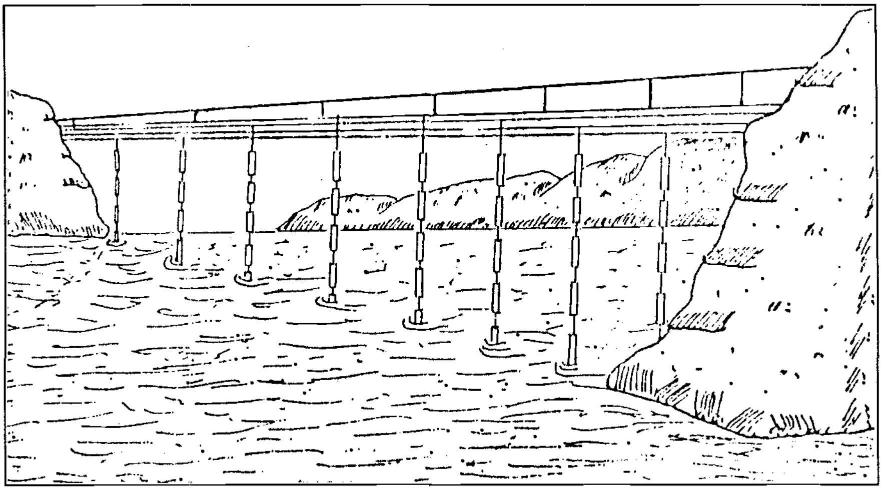

Fig. 2. Electric screen with a single row of electrodes and alternating current.

Applications of Multiple-Function and Large-Span Barrier Nets

Taipinghu reservoir, located in the north of Huizhou District in Anhui Province, is a valley-type reservoir. The reservoir has a surface area of 272 km^2, a length of over 50 km, and the maximum width of 4 km. The average annual flow is 2 770 million m^3 and the water level is controlled at 117 m during the flood season. About 2 million Chinese carp fingerlings are stocked into the reservoir each year.

A large special barrier with multiple functions was designed for Taipinghu reservoir in 1986. The barrier has three parts: a impounding net; a filtering net; and a double-platform device for boat passage (Fig. 3).

The barrier facility in the net is 450 m long and 70 m high. The barrier net is made of braided synthetic material (PE and PVA). The main webbing, auxiliary webbing, cover net, and bottom spread-net are supplemented with a head line, foot line, main head line, main foot line, and iron chains. The barrier net at a maximum water level of 117 m is primarily used to block movements of sliver, bighead, and grass carp larger than 0.5 kg (Table 1).

The position of the barrier is fixed by mounds of soil. When the barrier net is pushed by the water, the stress passes through the main head and foot lines, so that it is shared on both sides of the bank, thus increasing the hold of the whole net against the flood water.

The filtering net is a newly designed structure used to catch fish as well as prevent their escape. It is simple, convenient, low cost, and efficient (Xu 1983). It is a 50 × 20 × 15 m rectangle. Fish following the flow of the current are caught and enter the filtering net.

The fixed filtering net includes a body net (with bottom, side wing, and backside webbing), a cone-shaped net, and a cover net (with side, backside, and cone-shaped

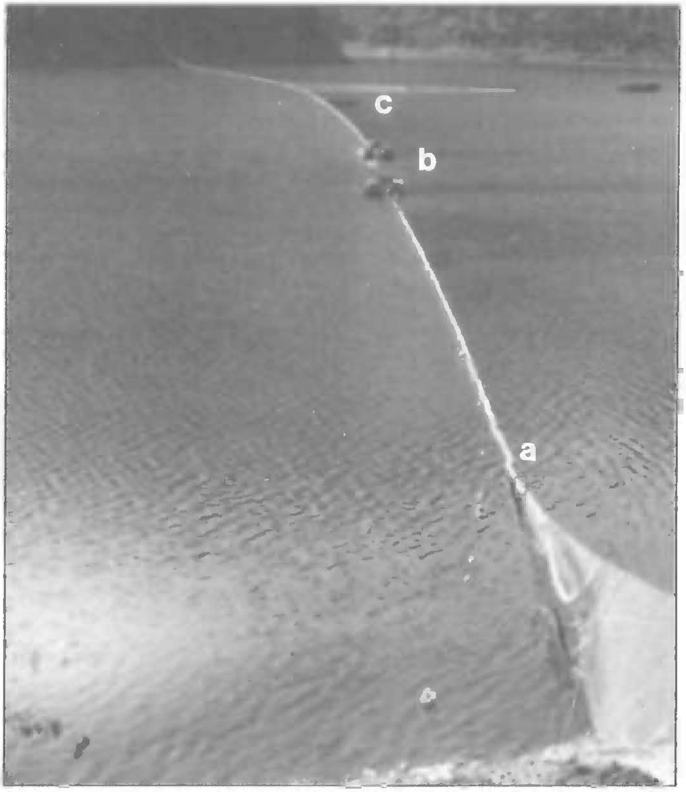

Fig. 3. Barrier net operated in Taipinghu reservoir: A. barrier net; B. double-platform device for boat passage; C. filtering net.

webbing). The body net and cone-shaped net are made of braided polyamide twine (mesh size 80–100 mm) and the rest is made of polyethylene twine (mesh size 100 mm).

During operation, the opening of the filtering net faces upstream to catch retreating fish. Filtering nets cannot be operated during the flood season.

A synchronous pulling system on double platforms above the water is used as a boat-passing device. This structure allows for quick operation, high efficiency, convenient maintenance, and safety.

The boat-passing device is composed of double cylindrical platforms, an electromagnetic braking hoist, electric controls, and automatic protection devices (Table 2). The platforms are two iron cylinders 1 m in diameter and 2 m long, made of 2.5-mm thick iron plate. The cylinders are cold rolled and welded closed.

The barrier-net project conducted in Taipinghu reservoir is the largest in China. Since it started operation in late October 1986, all devices have been functioning normally with beneficial economic and social effects (Xu 1989).

At present, barrier nets are operating economically in many Chinese reservoirs, such as Dongzhang reservoir (1983), Qixi reservoir (1984) in Fujian Province,

Table 1. Characteristics of barrier nets.

Characteristics	Dimension
Mesh sizes (mm)	80, 90, and 100
Maximum flow rate (m^3/s)	3 690
Area of the net (m^2)	16 834
Total resistance of the net in the water (kg)	9 165
Total weight of the net in the water (kg)	522.9
Total length (m)	
Head line	439
Foot line	475
Floating force (kg)	5 214
Sinking force (kg)	4 765
Applied force (kg)	
Head line or foot line	4 510
Bank mounds	8 883
Weight of each mound (kg)	265

Table 2. Characteristics of the boat-passing device.

Characteristics	Dimension
Boat passage dimensions (m)	30 × 3.5
Loading on platform (single) (kg)	1 000
Pulling force at a hoist (kg)	500
Average linear velocity of the hoist (m/min)	12
Time needed to make passing device operational (s)	12
Maximum loading of the excess-loading protection device (kg)	800
Total weight of double cylindrical platform (kg)	697.54
Buoyancy calculation of double cylindrical platform (t)	2.44

Touhu reservoir (1985), Taipinghu reservoir, (1986), Qianhu reservoir, and Sifanghu reservoir (1987) in Anhui Province.

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Biology and Fishery of the Catfish, *Mystus aor*, in the Kaptai Reservoir, Bangladesh

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Aspects of the fishery (1976–1988) and the biology of the commercially important catfish, Mystus aor, *in Kaptai reservoir (68 880 ha) are presented. The fish is predominantly piscivorous. The length–weight regression coefficients were 2.939 for male, 2.941 for female, and 2.890 for male and female combined. The relative condition factor* (Kn) *was 0.947–1.036 for males, 0.937–1.042 for females, and 0.965–1.036 for both sexes combined. The ratio of males to females was 1:0.724 ($\chi^2 = 11.73$, $p < 0.001$). Females attained sexual maturity at 48 cm. Ova diameter frequency suggested that the species breed once a year during the months of April to July. Diameter of eggs varied from 0.3504 to 0.9510 mm. Fecundity varied from 12 560 for a fish of 550-g body weight to 48 635 for a fish of 1 000-g body weight (mean 36 eggs/g body weight). Fecundity was positively correlated with body length, body weight, and ovary weight.*

Landing records (1976–1988) showed the highest catch of M. aor *was recorded in 1986 (144 863 kg, 5.95% of total catch) and the lowest in 1980 (9 924 kg, 0.33% of total catch). An increasing trend was found since 1981, which may be due to the high annual water-level fluctuation, high turbidity, and the use of effective fishing gear. Wooden boats and seine nets, popularly called* tengra jal, *are usually used to catch* M. aor *and other big predator fishes and major carps.*

Mystus aor (Hamilton) is one of the naturally occurring and commercially important freshwater catfishes of Bangladesh. It is also distributed throughout India and Burma (Day 1889). The fish, locally known as *ayre* or *guzi ayre*, belongs to the order Cypriniformes and family Bagaridae (Rahman 1989). Bagarid catfishes are among the most important food fishes in Bangladesh. Out of at least 13 species of Bagarid catfishes under four genera, only two species (*Rita rita* and *Mystus gulio*) are abundant in the estuaries and bay. All other members are primarily freshwater fish. The longest specimen of *M. aor* reported from Bangladesh was 94 cm in total length and 5 kg in weight (Rahman 1989). In India, the largest reported specimen was 112.0 cm (Day 1878). The fish is generally found in ponds, rivers and lakes in Bangladesh, but constant supply is only available from Kaptai reservoir.

In Kaptai reservoir, catfishes constitute a fishery of considerable commercial importance throughout the year and data relating to commercial landings over a period of 13 years revealed that their fishery ranks next to major carps, Clupeids

(*Gudusia chapra* and *Gonialosa manminna*), minor carps, and Notopterids (*Notopterus chitala* and *N. notopterus*). *Mystus aor* alone occupied 11th position.

Kaptai reservoir is one of the largest artificial lakes in the world (BLP/IDRC 1980), and the largest in Southeast Asia (Fernando 1980). It covers 68 880 ha (Ali 1985) and serves as a perennial source of 58 fish species including 5 exotic ones (Hafizuddin et al. 1989). Landing records (1976–1988) indicate that the average annual yield of fishes from this lake is 3 327 t.

In spite of their great economic value, very little is known about the fishery and biology of the catfishes, or other species, of Kaptai reservoir. In India, a few observations are made on breeding and feeding habits (Khan 1924, 1934; Raj 1940; Chacko and Kuriyan 1948) and on life history, bionomics, and breeding (Saigal and Motwani 1962) of catfishes. In Bangladesh, some work has been done on some other species and the limnological aspects of Kaptai reservoir (ARG 1986; Azadi et al. 1988a, b; Azadi and Nasiruddin 1989). A brief postimpoundment limnological study was made on Kaptai reservoir by Sandercock (1966).

No work had been done on *M. aor* in Bangladesh. In the present investigation, the following four studies were made on *M. aor* in Kaptai reservoir: first, length–weight relationship and condition factor; second, food and feeding habits; third, fecundity and reproductive strategy; and, fourth, aspects of the fishery for the period 1976–1988.

Description of Reservoir

Kaptai reservoir, also known as Kaptai Lake–Karnaphuli reservoir, is one of the largest artificial freshwater bodies in the world, and the largest in Southeast Asia. It was created in 1961 by damming the Karnaphuli River near Kaptai in the Chittagong Hill Tracts (lat. 22°29′; long. 92°17′). The reservoir was created for hydroelectric power generation, but also contributes to the production of a significant quantity of freshwater fish. It is also used for navigation, flood control, and irrigation.

The reservoir is "H" shaped, bearing two arms, joined by a narrow gorge near Shuvalong, a part of the old Karnaphuli River course. There are five main inflow rivers (the feeding canals): the Myani, the Kassalong, and the Karnaphuli in the right arm and the Chengi and the Reinkhiyang in the left arm.

There are about 58 fish species including 5 exotics in the reservoir. Of these species, 31 are commercially important (Hafizuddin et al. 1989). After its creation in 1961, the reservoir fishery was managed by the Directorate of Fisheries (DOF), Bangladesh. Since 1963, the lake's fishery has been managed by the Bangladesh Fisheries Development Corporation (BFDC).

Geologically, the lake area belongs to the Pliocene and Miocene epoch of the Tertiary period. The soil in the valley bottoms on level ground is clay-loam and that of the hills is sand or sandy-loam (Bangladesh, Forest Department 1973/74). The main types of forests are tropical wet evergreen, tropical moist deciduous, tropical open deciduous, and savanna in the Chittagong Hill Tracts area. However, in the watershed and in the near vicinity of the lake, except for Kasalong reserve forest, almost the entire watershed area has been deforested by shifting cultivation (*jhum*). The hills are now covered with scrub, bamboos, grasses, and shrubs, and the soil

Table 1. Environmental features of Kaptai reservoir.

		Source
Year of impoundment	1961	
Surface elevation (m)	31.1	ARG 1986
Surface area (ha)[a]	68 880	Ali 1985
	58 300	ARG 1986
Dry season, 20 March 1976	58 060	BLP/IDRC 1980
Full inundation, 28 October 1975	75 168	BLP/IDRC 1980
Peak dry season, 2 May 1973	27 216	BLP/IDRC 1980
Mean of dry, full level, and peak dry season	53 481	Authors' observation
Volume (annual mean) (10^6 m^3)	524.7	ARG 1986
Total mean annual discharge (10^6 m^3)	1 707.0	ARG 1986
Storage ratio	0.31	ARG 1986
Mean depth (m)	9	ARG 1986
Maximum depth (m)	33	Authors' observation[b]
Water level (1962–1989) (m)		
Mean fluctuations	8.89	KHPS[c]
Maximum	33.24	KHPS[d]
Minimum	19.26	KHPS[e]
Growing season (days)	365	ARG 1986
Mean specific conductance at 25°C (mS/cm)	106 ± 14	Authors' observation[b]
Mean water temperature (°C)	26.8 ± 2.54	Authors' observation[f]
Air temperature (1982–1988) (°C)		
Maximum	34.2 ± 0.6	KHPS
Minimum	18.3 ± 0.9	KHPS
Total rainfall (cm)		
Yearly mean (1964–1988)	260	KHPS
Maximum	369	KHPS 1976
Minimum	117	KHPS 1979

[a] 100 ha = 1 km^2.
[b] 1985–1987.
[c] Karnaphuli Hydropower Station, Kaptai.
[d] October 1963, 1989.
[e] June 1986.
[f] 1985–1986.

has been exposed causing erosion and siltation of the lake. For example, on 26 March 1975, landsat imagery showed the lake area was 619 km^2 (at 27 m above mean sea level (MSL)); whereas, on 20 March 1976, the area was reduced to 580 km^2 (at 27 m above MSL). The difference of 39 km^2 in surface area illustrates the degree of siltation (BLP/IDRC 1980). Some environmental features of the reservoir are given in Table 1.

Materials and Methods

Fish were collected from the catches at Shuvalong and Rangamati on the reservoir at regular monthly intervals from October 1987 to September 1988. Most of the fish were caught by seine nets with permissible mesh sizes (7.5–18 cm). These are popularly called *tengra jal* and are 150–300 m in length and 5–10 m in vertical depth. Catfishes are also caught by hook and line. Country-made wooden boats (10–11 m in length, 1–2 m in breadth, and 0.5–0.75 m in depth, operated by three or four fishermen) are generally used to operate the seine net.

A total of 250 *M. aor* were used to determine the length–weight relationship, which was established using the formula $W = aL^b$ (Le Cren 1951). The relative condition factor (*Kn*) was also calculated following Le Cren (1951). The condition factor (*K*) was calculated for different months as:

$$[1] \quad K = [(BW - GW)/TL]100$$

where *BW* = body weight, *GW* = gonad weight, and *TL* = total length.

The stomachs of 250 fishes and their gonads were dissected soon after collection, and preserved in 5% formalin for microscopic examination and further study. Food contents of the stomachs were analyzed (Hynes 1950; Pillay 1952). The relative importance of various food items was calculated using the Index of Preponderance (Natarajan and Jhingran 1961). The intensity of feeding was assessed by the degree of distension of the stomach in each fish (full, 3/4 full, 1/4 full, 1/8 full, and empty). Twelve mature ovaries were used for fecundity determination by the gravimetric method (Bagenal 1967). The diameter of the eggs was measured in the anterior, central, and posterior regions of the ovarian lobes. The gonadosomatic index (*GSI*) was calculated for different months as:

$$[2] \quad GSI = (GW/BW)100$$

The catfish fisheries of Kaptai reservoir are discussed on the basis of annual landing records for the last 13 years (1976–1988) obtained from the Rangamati station. Species data on a monthly basis were obtained for only 2 years (1984/85; 1985/86).

Results and Discussion

Length–Weight Relationship

Mystus aor ranged between 15 and 78 cm in total length and all 250 specimens were used to calculate the length–weight relationships. The relationships calculated for both the sexes, combined and separately, were as follows:

Male and female combined:

$$[3] \quad W = 0.00704693\ TL^{2.89};\ r = 0.996 \text{ or}$$

$$\log W = -2.152 + 2.89 \log TL$$

Male:

$$[4] \quad W = 0.00587489\ TL^{2.939};\ r = 0.995 \text{ or}$$

$$\log W = -2.231 + 2.939 \log TL$$

Female:

$$[5] \quad W = 0.00592925\ TL^{2.941};\ r = 0.995 \text{ or}$$

$$\log W = -2.227 + 2.941 \log TL$$

where *W* = weight and *TL* = total length.

The significance of the variation in the estimation of the regression coefficient from the expected value of 3.0 was tested by the *t* test. The values of regression

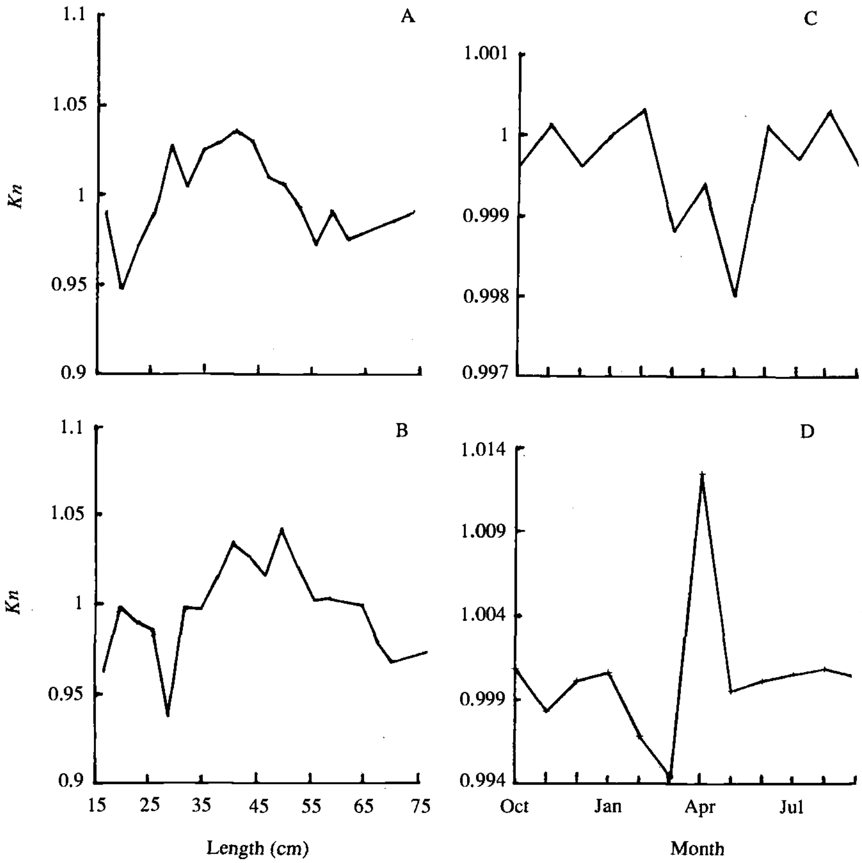

Fig. 1. Relative condition factors (*Kn*) of *M. aor*: A. Different size groups of males; B. Different size groups of females; C. Monthly variation for males; D. Monthly variation for females.

coefficient ranged from 2.77 to 3.01 (for combined sexes); 2.77 to 3.10 (for males); and 2.79 to 3.09 (for females) at a 95% confidence limit. The values followed the cube law and were not significantly different from the cube at the 0.05 level, which agreed with Martin (1949), Shafi and Quddus (1974), and Rao (1983). According to Pauly (1984), the exponent *b* lies between 2.5 and 3.5, usually close to 3. Carlender (1969, 1977) has demonstrated from a large number of length–weight data, stemming from a wide variety of fishes, that values of $b < 2.5$ or > 3.5 are generally based on a very small range of sizes or that such values of *b* are most likely erroneous.

Relative Condition Factor

The relative condition factor (*Kn*) of *M. aor* was calculated for each group and also for different months. Fig. 1 shows the relative condition factors for males and females of different size groups, and also for different months. The relative condition factor of male fishes (Fig. 1a) ranged from 0.947 (18–21 cm length group) to 1.036 (39–42 cm length group), with a mean value of 0.999. Figure 1b shows the *Kn* values of female fishes. The lowest *Kn* value of 0.937 was found in the 27–30 cm length group, the highest value (1.042) was found in the 48–51 cm length group, and the mean value was 0.997. For combined sexes, the *Kn* values ranged from 0.965 (15–18 cm) to 1.036 (39–42 cm), with a mean value of 0.999. Figures 1c and d shows the monthly relative condition factors. For males, the *Kn* value ranged from 0.9887 (May) to 1.003 (February) with a mean of 0.9988; for females, it varied from 0.9945 (March) to 1.0124 (April) with a mean value of 1.004.

Relative condition factors in different size groups in males and females were found to be higher mainly in the mid-size groups. Marked seasonal fluctuations of *Kn* values were observed. These may be due to changes in environmental conditions with the change of seasons that resulted in the changes in the amount of food supply and maturity of gonads. Variation in *Kn* values due to the above causes were also reported by Hickling (1930), Le Cren (1951), and Shafi and Mustafa (1976) for other fishes.

Food and Feeding Habits

The alimentary canal of *M. aor* is elongated and has a prominent stomach. Information on the fullness of stomachs and the monthly stomach composition of 250 *M. aor* is presented in Fig. 2. Out of 250 stomachs examined, 225 (90%) contained food and the rest (10%) were empty. This varied from month to month. Because little variation was observed in stomach contents with fish size, pooled data are presented for all size classes of fish.

The food items found in the stomachs were mostly: (1) fish (*Glossogobius giuris, Ailia coila, Punitius sophur, P. ticto, Amblyopharyngodon mola, Chanda ranga, C. lama, Gudusia chapra, Corica soborna, Mastacembalus pancalus* were most common); (2) fish remains (scales, bones, eyes, fin rays, and partly digested bodies); (3) insects (dragonfly nymphs, chironomid larvae, and some unidentified larvae); (4) bivalve molluscs (*Bellamya bengalensis* and *Thiara tuberculata* of gastropod molluscs were also found); (5) crustaceans (*Macrobrachium lamarrei* and its broken parts were the most common crustaceans); (6) plant matter (parts of leaves, stems of higher plants, dried grass leaves, and aquatic weeds); (7) debris (decayed organic matter); and (8) miscellaneous (partly digested food materials — mainly fish flesh, sand, and mud).

According to the Index of Preponderance, the consumed food items are graded as follows: (1) miscellaneous; (2) fish remains; (3) debris; (4) fishes; (5) plant matter; (6) insects; (7) crustaceans; and (8) molluscs. Among the food items, miscellaneous, which occupied the first position, consisted mainly of semidigested fish flesh; second position was occupied by fish remains; and fourth position by various species of fishes. This result clearly indicated that the fish is a piscivorous (carnivore) predator. Considering other items (molluscs, crustaceans, insects and insect larvae, and debris) it can be concluded that the fish is a bottom-feeding carnivore. The bottom-feeding nature of this fish is supported by the 17 groups of macrobenthic organisms recorded by ARG (1986) from Kaptai Lake. Saigal and Motwani (1962) found carnivorous feeding habits in *Mystus seenghala*; Bhuiyan and Hogue (1984) observed carnivorous feeding habits in *Mystus vittatus*.

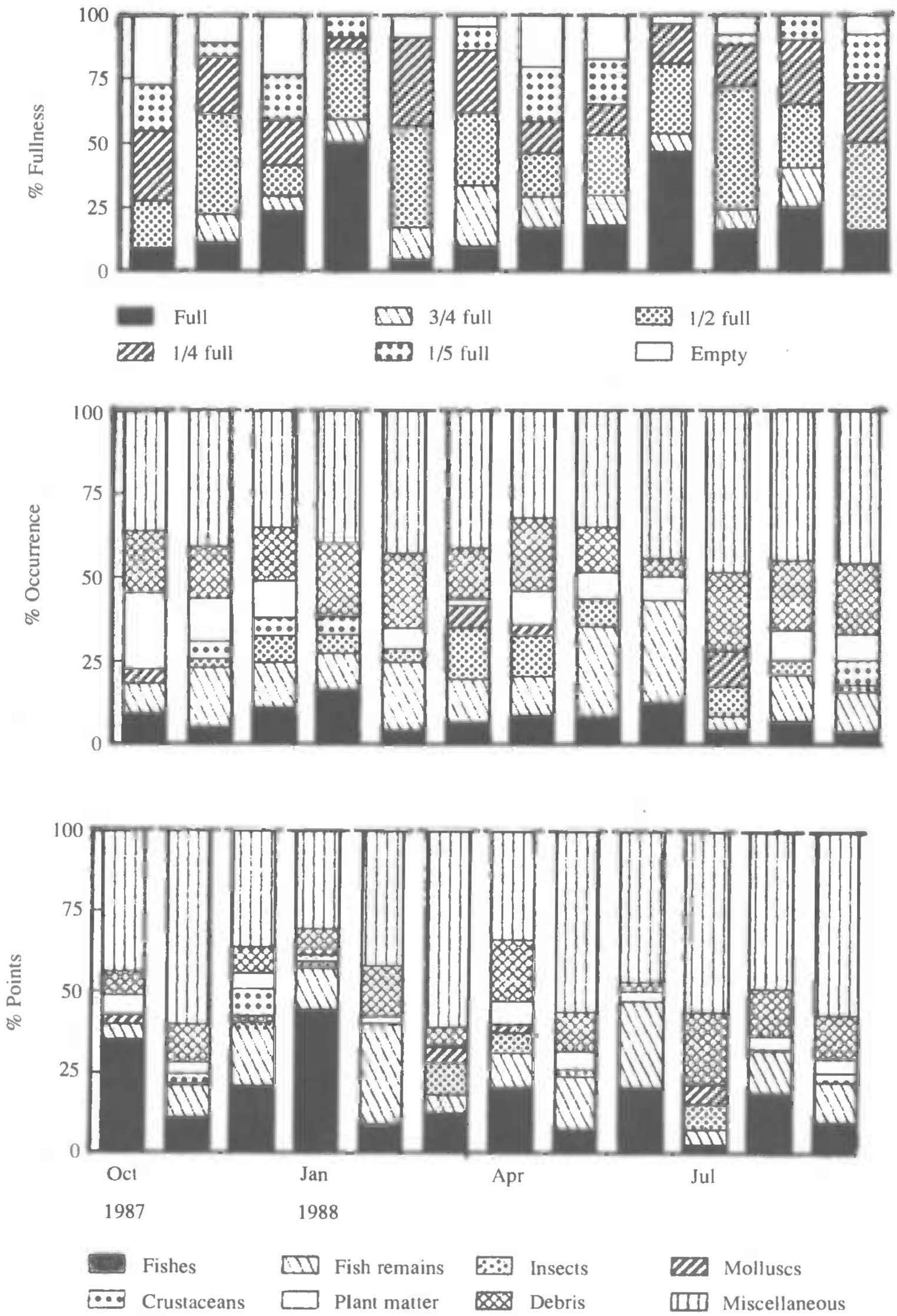

Fig. 2. Fullness of stomachs (A) and stomach contents by percentage of occurrence (B) and by percentage of points (C) for *M. aor*.

Sex Ratio and Maturity Cycle

Of 250 fishes sexed, 145 were males and 105 were females. The overall ratio was 1:0.724 (58% males; 42% females). The value of χ^2 for sex ratio was 11.73 (with 11 degrees of freedom), which was significant ($p < 0.05$ or < 0.001). Similar types of variation in sex ratio were also observed by Shafi and Quddus (1974), Shafi and Mustafa (1976), and Azadi et al. (1989) in other fish. Females were dominant in October, March, and April (prespawning period) and males were dominant the rest of the year. This is similar to the findings of Kader (1984) for *Goboides rubicundus*.

The ova diameter-frequency polygons in different months are depicted in Fig. 3. Immature intraovarian eggs were found in the ovaries throughout the year. The

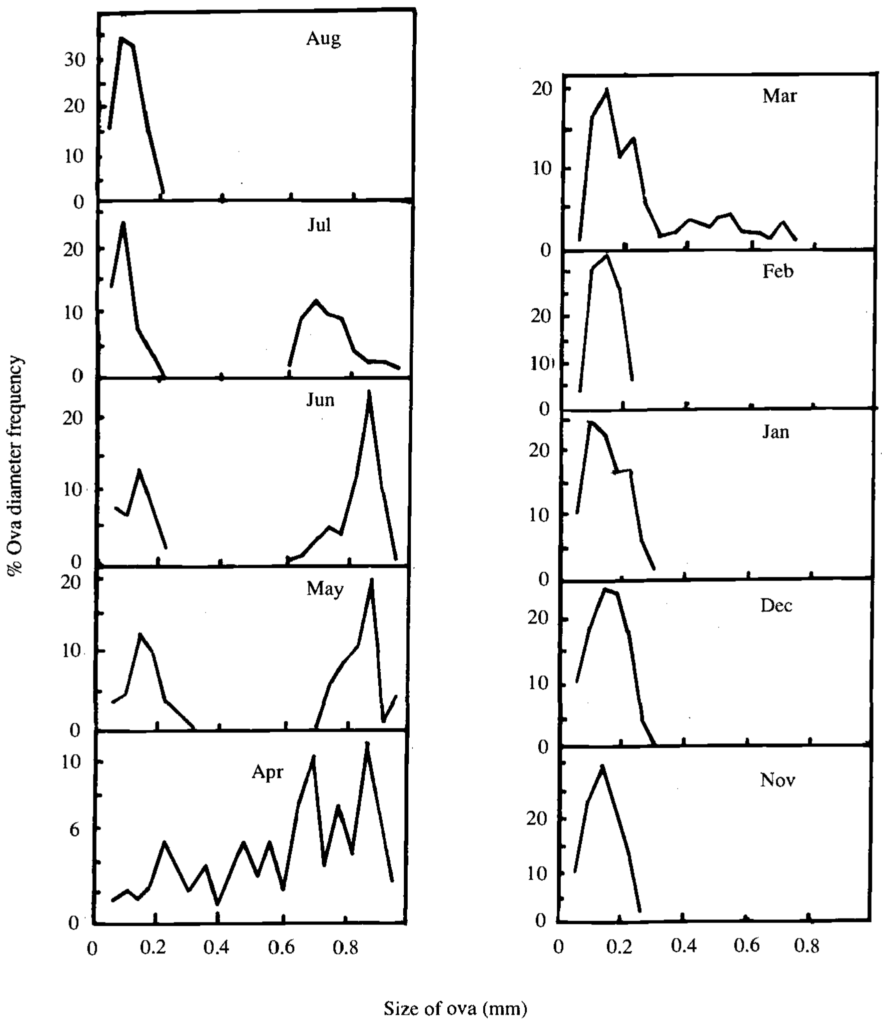

Fig. 3. Ova diameter frequency for *Mystus aor*.

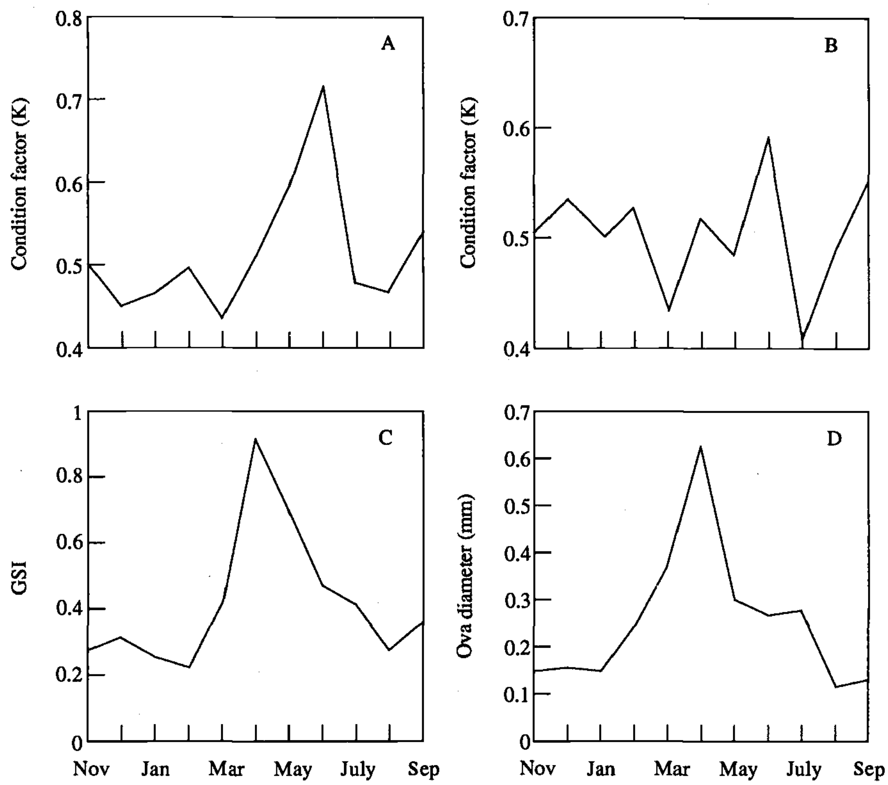

Fig. 4. Monthly condition factors (*K*) for (A) males and (B) females; and (C) gonadosomatic index (GSI) and (D) ova diameter.

ripening and ripe ova were found only from March to July. Diameter of eggs varied from 0.3504 to 0.9510 mm. Eggs started to develop from March. Progression in the average size of the ova from November to September (Fig. 4) shows that most of the ovaries matured during April, May, and June, which was also supported by the gonadosomatic index (GSI).

In the mature stages, there was only a single mode (May, June, and July) of ova. The spawning season of *M. aor* in the Kaptai reservoir is April to July. These results agree with the finding of Hancock (1979) with *Barbus barbus*, who reported that small- and medium-sized eggs were found throughout the year and that ripening eggs were found at the start of the spawning season. Females were found to attain maturity between 48 and 60 cm in length.

Gonadosomatic Index

The gonadosomatic index (GSI) of females (Fig. 4) shows that weight changes in the gonads correspond roughly to the three gametogenic stages: (1) during the prespawning period, November–February, a gradual increase of GSI; (2) a marked increase reaching a peak during the spawning period, April–July; and (3) a gradual decrease in the postspawning period, August–October. For the males, the lowest *K* value 0.4373 was found in March. This gradually increased and reached a peak ($K = 0.7107$) in June, with a mean of 0.5135. The fluctuation of K values was remarkable in the females, where the lowest value (0.4104) was observed in July and the highest value (0.5935) in June, with a mean of 0.507. The condition factor showed maximum values in the spawning months, except in the case of females where a small variation occurred from July. Similar observations were also made by Kader (1984) in *G. rubicundus.*

Fecundity

In *M. aor*, the ovary is bilobed, and the left ovary is slightly larger than the right. The mature ovary is yellowish in colour. Fecundity varied from 12 560 (for a fish 48 cm total length, 550 g body weight, and ovary weight 5.50 g) to 48 635 (for a fish 60 cm total length, 1 000 g body weight, and ovary weight 21.65 g). The mean fecundity of 12 females was 28 176, with mean total length 52.8 cm, mean body weight 778.8 g, and mean ovary weight 12.06 g. A mean of 36 eggs/g of body weight was recorded. Fecundity was positively correlated with body length, body weight, and ovary weight, which were highly significant at 0.1%. The relationships were:

Body length (L) versus fecundity (F):

[6] $\log F = -6.79 + 6.5 \log L$ ($r = 0.92$; $t = 7.22$)

Body weight (W) versus fecundity (F):

[7] $\log F = -3.046 + 2.581 \log W$ ($r = 0.91$; $t = 6.93$)

Ovary weight (OW) versus fecundity (F):

[8] $\log F = 3.396 + 0.975 \log OW$ ($r = 0.99$; $t = 28.57$)

The fecundity of *M. aor* increased with increases in body length, body weight, and ovary weight. This agrees with the results of Hickling (1940), Lehman (1953), Bagenal (1967), Doha and Hye (1970), and Azadi and Siddique (1986) with different species of fishes.

Fisheries

The reservoir harbours a variety of fish. The fishery is supported by major carps, minor carps, catfishes, murrels, notopterids, clupeids, and miscellaneous species. The major carps include *Catla catla*, *Labeo rohita*, *Cirrhinus mrigala*, and *Labeo calbasu*. The minor carps are *Labeo gonius*, *Puntius sarana*, and *Barbus* spp. The catfishes are *M. aor*, *Wallago attu*, *M. cavasius*, *Eutropiichthys vacha*, and *Ailia coila*. Murrels are *Channa striatus* and *C. marulius*. Notopterids are *Notopterus chitala* and *N. notopterus*. Clupeids are *Gudusia chapra* and *Gonialosa manminna*. The miscellaneous species are *Amblypharyngodon mola*, *Setipinna phasa*, *Oxygaster bacaila*, *Scainea coitor*, *Xenentodon cancila*, *Heteropneustes fossilis*, *Labeo bogha*, *L. bata*, *Mastacembelus armatus*, *Macrognathus pancalus*, and *Tor tor*. Some fish, mainly clupeids and some minor carps, are dried.

On the basis of 13 years (1976–1988) total landings (weight), the fish population of the reservoir consists of major carps (22.3%), minor carps (12.3%), predators (15.6% — catfish 7.0%, notopterids 7.7%, and murrels 0.9%), clupeids (21.6%), dry fish (wet weight) (25.1%), exotic species (0.01%) (carps and tilapia), and miscellaneous (2.7%).

Table 2 shows total landings of all fishes, yields (kg/ha), and yearly total landings of catfishes. The year of peak fishery output was 1984, when 4 242 t were caught. Over a 13-year period (1976–1988), yield averaged 62.21 kg/ha (when mean surface area was 53 481 ha) and 48 kg/ha (when surface area was 68 880 ha). The predicted (according to Henderson and Welcomme 1974) yield (using the morphoedaphic index) is 45 kg/ha. Dohu and Hye (1983) calculated 57 kg/ha yield for Kaptai reservoir. In Kaptai reservoir, the yield depends on various factors, i.e., water level, efficient fishing gear, number of people fishing, and political disturbances in the Hill Tract areas.

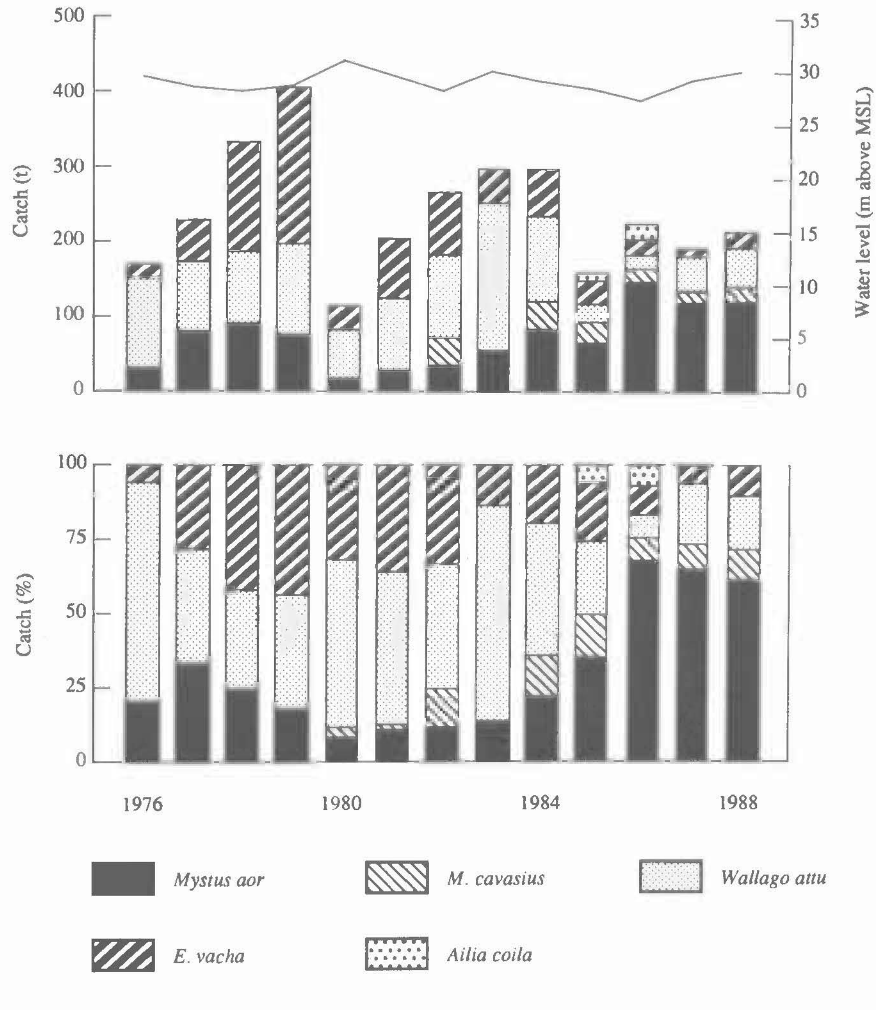

Fig. 5. A. Yearly landings of catfishes (thousands of kg) and water level (m above sea level); B. Landings in percentages.

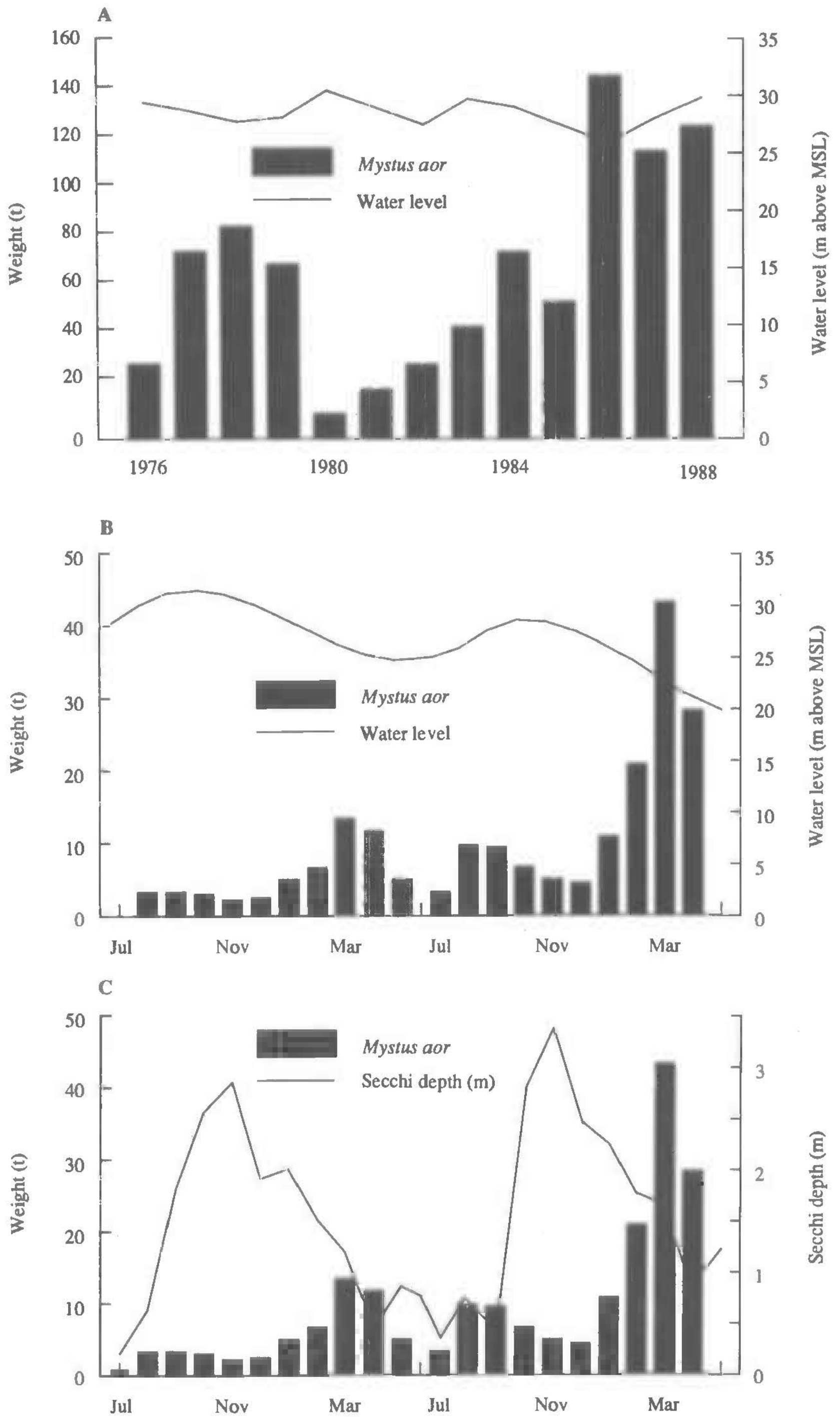

Fig. 6. A. Yearly landings of *M. aor* and water level; B. Monthly landings of *M. aor* and water level; C. Monthly landings of *M. aor* and Secchi depth.

Table 2. Total catch and catfish catch in Kaptai reservoir (1976–1988).

Year	Total catch (kg)	Yield (kg/ha)		Catfishes (kg)
		From 68 880 ha	From 53 481 ha	
1976	2 145 334	31.14	40.11	162 376
1977	2 448 300	35.54	45.77	230 208
1978	3 684 939	53.49	68.90	338 427
1979	3 544 748	51.46	66.28	398 538
1980	3 031 088	44.00	56.67	112 559
1981	3 768 797	54.71	70.46	198 596
1982	3 825 899	55.54	71.53	261 932
1983	3 917 474	56.87	73.24	301 300
1984	4 242 536	61.59	79.32	288 331
1985	2 701 775	39.22	50.52	138 239
1986	2 433 013	35.32	45.49	195 755
1987	3 980 760	57.79	74.43	180 767
1988	3 536 439	51.34	66.12	210 024
Mean		48.30	62.21	

Catfishes formed a sizable part of the landing in Kaptai reservoir (Fig. 5). Catfishes occupied 6th position among the nine categories, while *M. aor* itself occupied 11th position among the 31 commercially important species. The catfishes have occurred in a fairly good quantity in all years since 1976. The highest landing was recorded in 1979 (398 638 kg, 13.0%) and lowest in 1980 (112 559 kg, 3.7%). The second highest landings were of *M. aor*, which accounted for 29.0% of the total catfish catch for the 13-year period. The highest amount of *M. aor* was recorded in 1986 (144 863 kg, 16.4%) and the lowest in 1980 (9 924 kg, 1.1%). An increasing trend is found since then (Fig. 5), which may be due to high water-level fluctuation and high turbidity (Figs 5 and 6). The average monthly catch of *M. aor* was highest in March 1985 (12 754 kg) 1985 and was highest again in March 1986 (44 282 kg) (Fig. 6).

Other catfishes (*Wallago attu* and *Eutropiichthys vacha*) also are in fair abundance (Fig. 5). Water level and turbidity (Secchi depth) were found to play an inverse relationship with the yearly and monthly landings of catfishes.

Harvest of catfish and other fish showed a definite seasonal variation in the reservoir. The highest catch is in March and April followed by February, May, August, September, and October. In comparison with other Asian and African reservoirs, i.e., Rihand reservoir in India (66 000 ha, yield 11 kg/ha) (Dubey and Chatterjee 1977), Ubolratna reservoir in Thailand (41 000 ha, yield 55 kg/ha) (Pawaputanon 1982), Kariba reservoir (536 400 ha, yield 27 kg/ha), and Volta reservoir (848 200 ha, yield 53 kg/ha) (Kapetsky 1986), the Kaptai reservoir fish production (62 kg/ha) is relatively high.

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Changes in the Fish Fauna of Thale Noi, Thailand, from 1982 to 1989

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In 1982, 22 fish species (biomass 1 198 g/m^2) and, in 1989, 11 fish species (biomass 582 g/m^2) were found in Thale Noi. The fish were small herbivorous and small carnivorous species. In 1989, nine species had disappeared and eight new species were found, indicating ecological changes. Proper management and rehabilitation of Thale Noi is needed.

Thale Noi is the freshwater area of Songkhla Lake (the largest natural lake in Thailand). Songkhla Lake covers an area of 98 680 ha and is a lagoonal reservoir connected to the Gulf of Thailand. It is divided into three parts: a freshwater (upper) part, covering 70% of the lake surface; a brackish-water central area, covering 5%; and a seawater (lower) part, covering 25% (Bhommanonta 1979; Davy 1981). Thale Noi is a freshwater lagoon (about 25 km^2) connected to upper Lake Songkhla. Thale Noi and the upper part of Lake Songkhla contain a large number of aquatic weeds that bloom year-round. An estimated 140 625 t of aquatic weeds are harvested for animal feed (Fisheries Office, Phattalung Province 1979).

During 1981–82, 19 species of aquatic plants belonging to 15 families were found in Thale Noi, with an average biomass of 12 197 g/m^2 (average of 12 months): biomass ranged from 6 534 g/m^2 in February to 20 517 g/m^2 in October (Purintavaragul and Lheknim 1983). This study surveyed changes in fish species composition in Thale Noi from 1982 to 1989 to obtain baseline data for better utilization and management of Thale Noi.

Materials and Methods

Five experimental stations in Thale Noi were chosen after a brief field survey. Areas were chosen according to their plant ecosystems and geography. Station 1 was close to Thale Noi village and had dense submerged plants at a water depth of

Table 1. Total weight and biomass of fish in Thale Noi (five stations) during February–December 1982 and 1989.

Station	Total weight (g)													
	Feb		Apr		Jun		Aug		Oct		Dec		Mean ± SE	
	1982	1989	1982	1989	1982	1989	1982	1989	1982	1989	1982	1989	1982	1989
1	1 853.0	791.9	1 654.0	473.7	2 627.0	833.2	2 072.0	895.9	2 606.0	746.6	321.5	216.8	1 855.5 ± 346.3	659.7 ± 106.7
2	132.0	506.5	169.0	592.7	1 715.0	478.6	686.5	437.9	519.0	137.2	102.5	106.2	554.0 ± 251.4	376.5 ± 83.3
3	436.0	598.0	2 874.0	1 557.1	5 920.0	257.7	1 180.0	1 197.1	2 171.5	491.3	277.5	302.6	2 143.1 ± 858.7	734.0 ± 214.6
4	542.0	497.6	493.0	328.0	1 122.0	926.3	909.0	494.1	437.0	252.3	226.0	123.7	621.5 ± 134.9	437.0 ± 114.0
5	465.0	493.1	548.0	855.8	3 042.0	882.5	234.0	942.8	470.0	759.4	128.0	287.0	814.5 ± 450.2	703.4 ± 105.4
Total	3 428.0	2 887.1	5 738.0	3 807.3	14 426.0	3 378.3	5 081.5	3 967.8	6 203.6	2 386.9	1 055.5	1 036.5		
Mean	685.6	577.4	1 147.6	761.5	2 885.2	675.7	1 016.3	793.6	1 240.7	477.4	211.1	207.3	1 197.7	582.1
SE	300.0	56.9	499.1	216.9	830.0	131.1	306.0	143.4	473.8	126.2	42.1	40.4	370.6	88.9
Mean biomass (g/m^2)	1.3	1.2	2.2	1.7	5.6	1.5	2.0	1.7	2.0	1.0	0.4	0.4	2.3 ± 0.7	1.3 ± 0.2

Note: Biomass and total weights were not significantly different ($p > 0.05$).

Table 2. Number of fish species in Thale Noi (five stations) during February–December 1982 and 1989.

	Feb		Apr		Jun		Aug		Oct[a]		Dec		Mean ± SE	
Station	1982	1989	1982	1989	1982	1989	1982	1989	1982	1989	1982	1989	1982	1989
1	22	13	17	14	17	13	15	13	17	9	14	10	17 ± 1.12	12 ± 1.30
2	9	12	13	14	13	11	13	13	13	8	15	10	13 ± 0.80	11 ± 0.91
3	13	17	15	13	21	8	16	15	15	8	11	11	15 ± 1.38	12 ± 2.09
4	10	9	8	11	12	13	10	10	10	9	12	9	10 ± 0.61	10 ± 0.67
5	16	12	13	13	16	12	8	12	11	9	10	10	12 ± 1.33	11 ± 0.83
Range	9–22	9–17	8–17	11–14	12–21	11–17	8–16	10–15	10–17	8–9	10–15	9–11		
Mean	14	13	13	13	16	11	12	13	13	9	12	10	14	11
SE	2.35	1.28	1.50	0.52	1.59	1.00	1.50	0.78	1.28	0.30	0.93	0.29	0.52	0.70

[a] Significantly different ($p < 0.05$) between 1982 and 1989.

Table 3. Changes in fish species in Thale Noi in 1982 and 1989 from surveys from five stations (+ = found; – = not found).

	Feb		Apr		Jun		Aug		Oct		Dec	
Station	1982	1989	1982	1989	1982	1989	1982	1989	1982	1989	1982	1989
Species not recorded in 1989												
Fam. Mastacembelidae												
Mastocembelus circumcinctus	+	–	–	–	–	–	–	–	–	–	–	–
Fam. Cyprinidae												
Subfam. Rasborinae												
R. daniconius	+	–	+	–	+	–	+	+	+	–	+	–
Subfam. Cyprininae												
Cycloecheilicthys lagleri	+	–	+	–	+	–	+	–	+	–	+	–
Fam.Bagridae												
M. micracanthus	+	–	+	–	–	–	–	–	–	–	–	–
Fam. Belonidae												
Xenetodon canciloides	+	–	+	–	–	–	+	–	+	–	+	–
Fam. Hemiramphidae												
Hemiramphus unifasciatus	+	–	+	–	+	–	+	–	+	–	–	–
Fam. Osphronemidae												
Irichogaster trichopterus	+	–	+	–	+	–	–	–	+	–	+	–
Fam. Centropmidae												
Chanda siamensis	+	–	+	–	+	–	+	–	+	–	+	–
Fam. Lobotidae												
Datnoides quadrifasciatus	–	–	+	–	+	–	+	–	+	–	+	–

New species recorded in 1989

Fam. Nandidae												
Nandus nebulosus	–	+	–	–	–	+	–	+	–	+	–	+
Fam. Tetraodontidae												
Tetradaodon leiurus	–	–	–	–	+	–	–	+	–	+	–	+
T. loetiti	–	–	–	–	–	–	–	+	–	+	–	–
T. palembengensis	–	+	–	+	–	+	–	+	–	+	–	+
Fam. Chandidae												
Chanda ranga	–	+	–	+	–	+	–	+	–	+	–	+
Fam. Clupeidae												
Corica soborna	–	+	–	+	–	+	–	+	–	+	–	+
Fam. Gobiidae												
Subfam. Gobiodae												
Brachygobius nunus	–	–	–	–	–	–	–	–	–	+	–	–
Subfam. Gobiodontinae												
Gobiopterus chuno	–	+	–	+	–	+	–	+	–	+	–	+

1–1.8 m. Station 2 was 1 km away from station 1 and was located at the southern part of Thale Noi reservoir close to the reservoir shore. Submerged aquatic plants were abundant, but not as dense as at station 1. Water depth was 1.2–2 m. Station 3 was situated in the eastern part of the reservoir close to the Khlong Nang Riam outlet of Thale Noi, which empties into the upper part of Songkhla Lake. Water depth was about 1.2–2 m. Station 4 was in the middle of Thale Noi. Water depth was 1.2–2.5 m (the deepest part of the reservoir). Station 5 was situated in the northwest of the reservoir near Khlong Khreng. The station is near the inlet of Thale Noi, which drains 7 000 ha of melaleuca tree forest (*Melaleuca leucadendra*) in the northern watershed of Thale Noi. The water depth was 1–1.8 m, with 60 cm of thick soft sediment.

An 80-m long nylon seine net of 0.5-cm mesh size was used to take triplicate random samples at each station. Sampling was carried out every 2 months during 1982 and 1989 (February, April, June, August, October, and December). Fish were identified and weighed.

Results

The biomass of fish in Thale Noi (five stations) in 1982 and in 1989 was not significantly different (Table 1); however, the mean biomass in 1982 was higher (2.3 g/m^2) than in 1989 (1.3 g/m^2). Fish biomass at stations 1 and 3 showed a 60% decrease from 1982 to 1989 (Table 1). The number of fish species in Thale Noi was not significantly different in the surveys, except in October (Table 2).

Fish species composition in Thale Noi during 1982 and 1989 is shown in Table 3. Nine species disappeared from the lake, and eight new species were found in 1989. Fishes of the families Nandidae, Tetraodontidae, Chandidae, Clupeidae, and Gobiidae were newly recorded in 1989. Fishes of the families Mastocembelidae, Lobotidae, Belonidae, Hemiramphidae, Osphronemidae, Centromidae, Cyprinidae, and Bagridae had disappeared since 1982.

Discussion

Thale Noi is a very shallow lake with a water depth of 1–2 m (Tansakul 1985). The pH is generally low (e.g., pH 3 at station 3 during the rainy season) (Tansakul 1985; Wongwit and Taweesak 1987). The acidic water may be the cause of small fish size observed in 1982 and 1989 (Table 3).

The number of fish species found in the lake in 1982 and 1989 was relatively low. The maximum number of 22 found in February 1982 is less than one-quarter of the number found in Tasek Bera (95 species), a similar lake in Malaysia (Mizuno and Furtado 1982). Half of the fish species found in Thale Noi were small herbivores and the other half were small carnivores (Table 3), reflecting the habitats of the lake where aquatic plants, phytoplankton, and zooplankton dominate (Angsupanich 1983; Purintavaragul and Lheknim 1983; Tansakul 1983).

Average fish biomass was low; there was a trend of decreasing biomass from 1982 to 1989, but the difference was not statistically different. The level of fish biomass found in the lake was lower than the average fish biomass found previously in reservoirs in Thailand (Chookajorn and Bhukaswan 1988).

During 1982–83, the fish catch of the Thale Noi fishing community was 7.6 kg/day per household. People fished 18 days/month (ISTT 1982). Seventeen species of freshwater fish were caught. *Pristolepis fasciatus* was the dominant species. Only 7 of 19 species were caught year-round (Rittibhonbhun et al. 1983).

Nine species of fish were locally extinct in 1989, and eight new species were found in Thale Noi. This demonstrates that changes in fish ecology and fish habitats occurred in Thale Noi. The appearance of the family Clupeidae (brackish-water species) in 1989 may indicate a low input of water from the watershed area and the intrusion of saline water from Songkhla Lake to Thale Noi.

Acknowledgment

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Management of the Fishery of Fuqiaohe Reservoir, Hubei Province, China

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The hydrobiology and the fishery of Fuqiaohe reservoir and their interrelationships are discussed. The management techniques used for the development of the fishery and the potential of the fishery are emphasized. The yield in the reservoir was better correlated to the number than to the weight of fingerlings stocked.

Fuqiaohe reservoir, a multipurpose reservoir (31° N, 115° E) of 1 493 ha was impounded in 1960 and is located in the northeast part of Hubei province. It has a storage capacity of 2.9×10^8 m^3. It is considered a large reservoir according to the classification used in China. Since 1975, the Institute of Reservoir Fisheries has been working in conjunction with the administration office of Fuqiaohe reservoir on production trials and management of the fishery. The yearly yield was 250–350 t for the last decade, which is comparable to the average fish yield of reservoirs in Hubei Province.

The management practices that have enabled the yield to be increased considerably over the last decade are presented.

Materials and Methods

The data on climatic parameters of the reservoir were collected from the local hydrographic station. The limnology of the reservoir has been investigated regularly from 1975 to 1989. Sampling methods are based on the criterion of investigation for inland water fishery natural resources. All data were analyzed on an IBM microcomputer.

Results

The reservoir is situated between the middle and lower reaches of the Yangtze River. The climate (Table 1) is such that fish can grow for about 210 days per year. The physicochemical parameters and phytoplankton, zooplankton, and benthic biomass are shown in Tables 2 and 3.

Table 1. The climatic factors of Fuqiaohe reservoir.

	Period	
	Average year	Apr–Oct
Rainfall (mm)	950–1 500	946.6
Sunshine		
Hours	2 114	1 416
Percent	48	32
Radiation (J/cm^2)	3 474	344
Temperature (°C)	16.5	22.2
Water temperature (°C)	16	25.3

Table 2. The main limnological data for Fuqiaohe reservoir (average for the years 1980–1987).

Parameter	Units	Value
Primary productivity	g O_2/m^2 per day	3.79
Chemical oxygen demand	mg/L	8.7
PO_4	mg/L	0.024
NO_3	mg/L	0.031
Total N	mg/L	0.70
Total P	mg/L	0.06

Table 3. The hydrobiological biomass of Fuqiaohe reservoir (average for the years 1980–1987).

	No./L	mg/L
Phytoplankton	5.5×10^5	2.6
Zooplankton	1.2×10^4	4.6
Benthos	1.04×10^3	2.4

Like most reservoirs in China, the Fuqiaohe reservoir fishery is essentially a stock and capture fishery. The main cultivated fishes are silver and bighead carps, which constitute 80–90% of the stocked species and yields. The fish yield of Fuqiaohe reservoir since its impoundment is shown in Fig. 1. The yearly yields have fluctuated, and five stages in the development of the fishery can be recognized: stage 1 (1963–1966), the ascendant period when fish yield was 415 t/year; stage 2 (1967–1969), the period when the yield was 180 t/year; stage 3 (1970–1775), when the fish yield was only 90 t/year; stage 4 (1976–1979), the restoration period when the average yield increased to 210 t/year; and stage 5 (1980–1989), the increase and steady period when the average fish yield was 270 t/year during which the highest yield of 350 t was recorded in 1988 (234 kg/ha). This is above the average yield of 214 kg/ha recorded for Chinese reservoirs.

The total stocking was 745 t from 1979 to 1989, or 68 t/year (45 kg/ha). The ratio of stock to yield was 1:4.5. In the pre-1984 and post-1983 period the ratios were 1:5.4 and 1:3.6, respectively.

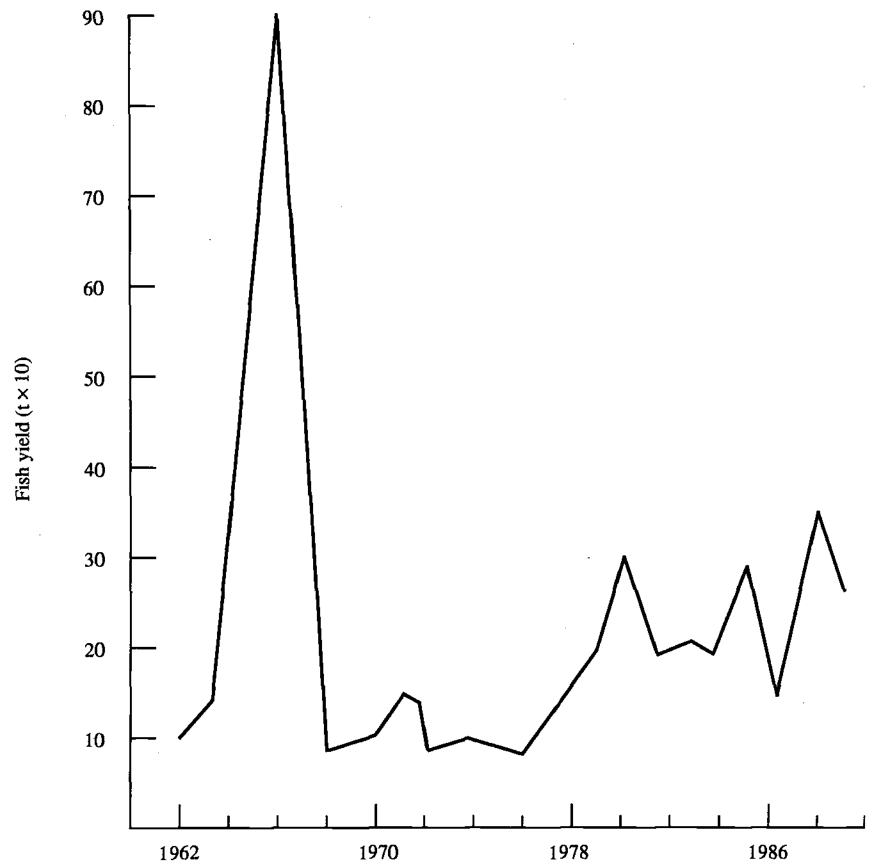

Fig. 1. Yearly fish yield in Fuqiaohe reservoir.

In the years when yield was lowest (1969 and 1975), the main species caught was *Elopichthys bambusa*, a predatory species. Since 1975, capturing of predatory fish was undertaken. About 50 t of adult and fingerling *E. bambusa* were landed in 1975. Consequently, the mortality of the stocked species was reduced. Concurrently, the viability of stocked species was enhanced by increasing the stocking size. The introduction of the united fishing methods (see Li, S., this volume) enabled the recapture rate to be increased. Acoustic and electric fishing also increased the recapture rate.

The fishery practices in Fuqiaohe reservoir indicate that fish yield was directly related to the stocking density after the predatory fishes were controlled. The relationship of stocking rate to yield of Fuqiaohe reservoir from 1979 to 1988 was linear (Fig. 2):

[1] $Y = 2.251 + 0.178X \ (r = 0.41)$

The yearly yield, however, was better correlated to the numbers stocked and the relationship was quadratic:

[2] $Y = 0.09 + 0.214X - (4.07 \times 10^{-4})X^2 \ (r = 0.97)$

The problem of fingerling supply is best solved by raising fry to fingerling in nets in the reservoir using the natural food resources. More than 100 t of the fingerlings of silver and bighead carps can be produced each year in the reservoir, of which about 50% are reared in several coves (60 ha) and 50% are reared in cages (2 ha) where the cultivated fingerlings are not fed with artificial food (Table 4).

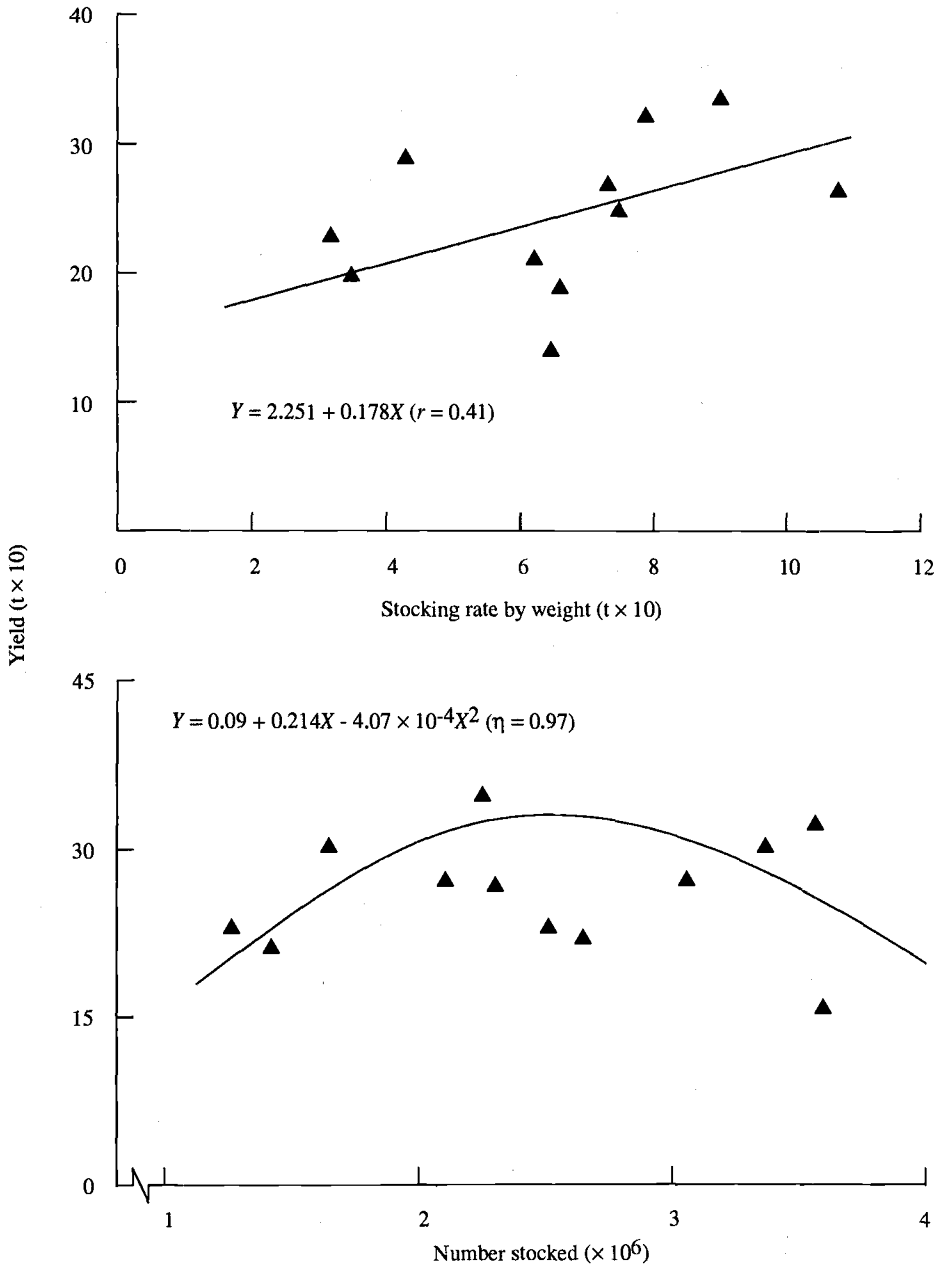

Fig. 2. The relationship of yield to stocking rate in Fuqiaohe reservoir.

Table 4. The results of fingerling culture in nets and coves in Fuqiaohe reservoir in 1989.

	Site	
	Nets	Coves
Area (ha)	1.83	63.3
Yield (10^4 kg)	6.71	5.99
Profit (CNY)[a]	7.74×10^4	7.31×10^4

[a] 1 USD = 4 CNY.

Discussion

Investigations show that Fuqiaohe reservoir has favourable physicochemical characteristics and abundant food resources for fish growth. Lin (1986) summed up the investigation of 74 large, middle, and small reservoirs in Guangdong Province and correlated fish yield to the main nutrients of the reservoirs. According to him, the fishery potential of the rich-nutrient reservoirs is above 375 kg/ha, middle-nutrient reservoirs 120–350 kg/ha, and poor-nutrient reservoirs less than 150 kg/ha.

In reservoirs in China, polyculture is practiced and silver and bighead carps are the abundantly stocked species. Based on the plankton biomass, Fuqiaohe reservoir should have a fish yield of about 310 kg/ha. However, the highest yield obtained was 234 kg/ha when the stocking rate was 70 kg/ha. This perhaps indicates that some other resources, such as the minor cyprinids, have not yet been utilized.

Chen et al. (1978) analyzed the yields of 106 reservoirs in the middle and lower reaches of the Yangtze River and classified them into four types:

- Those in which the yield would increase with increased stocking;
- Those in which the fish yield would fluctuate but be higher than the average for the province;
- Those in which the fluctuations would be lower than that of the second groups; and
- Those in which the yield would decline sharply and have no relationship to stocking.

At first, Fuqiaohe reservoir belonged to the fourth type. However, since 1976 with the almost complete elimination of the predatory *E. bambusa*, the yield has increased significantly, and now the yield of Fuqiaohe reservoir is related to the stocking rate.

De Silva et al. (in press) studied the relationship of stocking and yield for several reservoirs in China. They found that at lower stock densities, the relationship of the mean yield (in weight per unit area) to the stocking rate was linear, but that the yields decreased when the stocking rate increased beyond a certain level. The stocking rate that gave maximum yield appeared to be dependent on, and influenced by, the reservoir size. Accordingly, we find from the yield curve of Fuqiaohe reservoir that the best stocking rate is 54 kg/ha in weight or 1 600 fingerlings/ha (Fig. 2). These results are comparable to those obtained by De Silva et al. (in press) for Fenheshuiku in Shanxi Province, which has the same water area. But the stocking density giving the maximum yield in Fuqiaohe reservoir is higher than that in Fenheshuiku, which is probably due to better management.

The practices in Fuqiaohe reservoir indicate that with proper management, higher yield can be obtained and economic efficiency increased.

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Discussion: Section 2 — Postimpoundment Changes

In this session, which included case studies from three countries, it was apparent that the available knowledge on the influence of tidal barrages on the migration of commercially important species such as *Lates calcarifer*, the mullets, and eels was very scanty. It was agreed that this was an area where research input was urgently needed.

The Chinese practice of installing barriers to prevent escape of "stocked" fish received much attention. It was apparent that in new reservoirs, in China, such installations, as well as other fishery activities, are considered at the planning stages. This is in contrast to the practices in most other countries in Asia where fishery activities are given little or very scanty attention during the planning stages.

It was pointed out that the type of barrier to be installed depends on the reservoir hydrology and morphometry as well as the availability of material. For example, in northern China, bamboo barriers are not installed because the material is unavailable and expensive. The unit cost of installation of different types of barriers were, unfortunately, not available. The Chinese scientists were, however, equivocal that such improvisations were cost-effective, particularly for those reservoirs that depend on regular stocking.

Much of the discussion centred on the paper on Kaptai Lake, Bangladesh. This is the largest reservoir in Asia, and the carnivorous catfish, *Mystus aor*, predominates the fishery. It was felt that much research effort is needed to understand the reproductive biology of this species, and the relationship of the fishery to water-level fluctuations.

It was felt that, in general, there is a dearth of information on the reproductive habits of naturally recruited species, except perhaps the tilapiines in Asian reservoirs, and that this has hindered improvising regulatory measures such as closed seasons and closed areas.

The paper on the fishery of Fuqiaohe reservoir, People's Republic of China, highlighted the influence of predator control on a stock–recapture reservoir fishery; a lesson to be learned in the management of reservoirs in which the fishery is dependent on stock–recapture. It was agreed that the predator was successfully eliminated because its reproductive biology was well understood and the reservoir authorities permitted improvisation of barriers to prevent recruitment from the main river source; another example of coordination and cooperation between fishery and reservoir managers.

In China, all reservoirs come under the jurisdiction of the Ministry of Water Resources. It was also evident that reservoir fisheries are managed by a reservoir bureau that includes fishery managers who work in consultation and conjunction with irrigation, hydroelectric, and catchment management personnel. This integrated management approach is practiced throughout China and, as a result, the reservoir fish yield has increased significantly over the last decade. In effect, in most small- and middle-sized reservoirs in China, fisheries is not considered as a secondary use, but as a primary use.

Section 3 —
Management and Modeling

Recent Advances in Reservoir Fisheries Management in India

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Indian reservoirs exceeding 3 million ha in area are recognized as an invaluable resource for inland fish production. Lack of a firm data base and the absence of a technological strategy until the late 1960s prevented any planned development of reservoir fisheries. Research conducted at the Central Inland Capture Fisheries Research Institute and elsewhere in the country during the last three decades has led to an understanding of the ecodynamic principles operating in Indian reservoirs. On average, the production from large reservoirs can be raised to 50–100 kg/ha per year, and increased to 100–300 kg/ha per year from small reservoirs. In Govindsagar reservoir, enlargement of mesh size, and increase in fishing effort coupled with consistent stocking, brought about a spectacular increase in catch from 273 t in 1975 to 753 t in 1978. Similarly, in Bhavanisagar reservoir, production was increased from 90 t in 1971 to 300 t in 1979. Whereas the large reservoirs are managed principally by stock manipulation, fishery regulation, and habitat management, the biologically more-productive small reservoirs are best developed by adopting a stocking policy based on estimation of biogenic capacity of the water body and a near-complete annual harvest. Such an approach has paid rich dividends in case studies in small reservoirs like Gulanya (150 ha), Bachhra (140 ha), and Aliyar (646 ha) where production levels were enhanced to 100, 140, and 202 kg/ha per year, respectively, in 2–4 years.

Efforts are underway to improve existing models for assessing qualitative indices of productive potential and to determine fish yield with greater resolution and higher precision. The reservoir fisheries is also being evaluated as an industry from a socioeconomic perspective so that enhanced fish yields lead to higher remuneration for those who fish, and generate adequate employment opportunities. The role of cooperatives is being encouraged to eliminate the middlemen and private money-lenders. By adopting improved techniques and developing infrastructure facilities, the Indian reservoirs should be able to contribute 0.322 million t of fish annually by the turn of the century.

Reservoirs constitute the prime inland fisheries resource in India. A major increase in inland fish yield is expected from reservoirs because of construction of a number of new dams and to improvements in reservoir-fisheries management. The growth of inland fisheries has been phenomenal in the last four decades. Fish production has increased from 0.22 million t in 1951/52 to 1.4 million t in 1988/89. The country has targeted 4.5 million t from freshwater resources by the turn of the century, and an average growth rate of 22.4% is therefore imperative.

At present, 22% of the freshwater area and 5.8% of the brackish waters are used for inland culture fisheries. Even at a maximum utilization of 50%, by the year 2000 their contribution will be limited to 1.24 million t. Inevitably, to realize the target, maximum reliance must be placed on capture fishery, and reservoirs will be the mainstay.

Existing Resources and their Potential

The development plan for India, extending up to 2010, envisages bringing 58 million ha of the 113 million ha of arable land under irrigation, resulting in the formation of a number of reservoirs. The total surface area of reservoirs in India was estimated by the National Commission on Agriculture (NCA) in the mid-1970s at 3.0 million ha and this is expected to grow to 6.0 million ha by the turn of the century (Anon. 1976). Srivastava (1984) compiled a list of 975 large and medium reservoirs in the country having an estimated area of 1.7 million ha. The biological potential of these resources was not evaluated until 1970 when fish yield from them stood at 5–8 kg/ha per year (Anon. 1976). The Central Inland Fisheries Research Institute (CIFRI) started an All India Coordinated Research Project on Ecology and Fisheries of the Reservoirs 1971 and gave a new dimension to the sporadic work carried out until then. Consequently, limnology suggested norms for raising the yield from reservoirs. In the course of a decade, the average fish yield from reservoirs rose to 15 kg/ha. These studies also improved technical capabilities and provided guidelines for change. The remarkable increase in the fish yield from 25.56 to 80.0 kg/ha in Bhavanisagar in Tamil Nadu, and from 25.0 to 76.5 kg/ha in Gobindsagar in Himachal Pradesh, are excellent examples of the value of the management strategies.

Determinants of Reservoir Productivity

Dams radically alter the river hydrology and create a new artificial aquatic environment. Productivity in such ecosystems is influenced by the climate and by edaphic and morphometric features. The geographic location influences the final productivity through climate, nutritional supply, and basin characteristics. Area, mean depth, and shoreline features are the most significant morphometric attributes. Over 200 Indian reservoirs have been subjected to ecological and fishery investigations. Based on the data gathered over the last two decades, it is possible to classify the reservoirs for management purposes based on their levels of productivity.

Large Multipurpose Reservoirs

Large reservoirs invariably are built on rivers in the mountain tracts, and submerge dense vegetation. This deviation from the conventional evolutionary course, and the rapid change from a lotic to lentic habitat, results in a trophic upsurge. The initial fertility reaches a maximum within 3–4 years. After passing through trophic depression, the reservoirs attain their final fertility in about 20–30 years. This final fertility is greatly dependent on allochthonous inputs from catchment areas. Long-term fishery management strategy has evolved from this final biological productivity level. The trophic depression in small reservoirs is avoidable through ecosystem management.

Physicochemical Limnology

The well-known ecological principles that operate in tropical reservoirs are not dealt with in detail in this paper. Rather, attention is paid to the features that influence fishery management procedures. The physicochemical properties of Indian reservoirs, and their categorization based on productivity, are given in Table 1.

Stratification

The temperature regime of the reservoirs in northern India is lower than those in the peninsular region. Some reservoirs of northern India show thermal stratification during the summer, with a difference of 10°C between the surface and the bottom (Gobindsagar and Konar reservoirs). With no thermal or chemical stratification, the temperature difference between surface and bottom layers in southern reservoirs is only 3–4°C.

Oxygen metabolism provides a dependable index of reservoir productivity (Natarajan 1979). A klinograde pattern of oxygen distribution, indicative of productive reservoirs, was recorded in Bhavanisagar, Nagarjunasagar, and Gobindsagar. In unproductive waters such as those of Konar, Tilaiya, Rihand, Tungabhadra, an orthograde oxygen distribution was observed.

Mean Depth

Mean depth, rather than depth alone, portrays many morphometric features, all of which contribute to potential productivity. Rawson (1955) observed distinct inflexion in the mean depth curves at 18 m (this has been recorded in some Indian

Table 1. Physicochemical features of selected Indian reservoirs (range of values).

Parameters	Overall range	Productivity		
		Low	Medium	High
Water				
pH	6.5–9.2	<6.0	6.0–8.5	>8.5
Alkalinity (ppm)	40–240	<40.0	40–90	>90.0
Nitrates (ppm)	T–0.93	N	<0.2	0.2–0.5
Phosphates (ppm)	T–0.36	N	<0.1	0.1–0.2
Specific conductivity (µmhos/cm)	76–474	—	<200	>200
Temperature (°C)[a]	12.0–31.0	18	18–22	>22
Soil				
pH	6.0–8.8	<6.5	6.5–7.5	>7.5
Available P (mg/100 g)	0.47–6.2	<3.0	3.0–6.0	>6.0
Available N (mg/100 g)	13.0–65.0	<25.0	25–60	>60.0
Organic carbon (%)	0.6–3.2	<0.5	0.5–1.5	1.5–2.5

Note: T = trace; N = negligible.
[a] With minimal stratification: i.e., <5°C.

reservoirs at 10 m). This suggests that the water mass below this depth serves as a nutrient sink that removes nutrients from the trophogenic zone, in the form of settling seston and phytoplankton, when density stratification is in effect.

Basin Soil

The chemical characteristics of the water in a reservoir are a reflection of the properties of the bottom soil. Soils with less than 3 mg of available phosphorus per 100 g of soil are poor, 3–6 mg/100 g soil is average, and above 6 mg/100 g soil is highly productive. Available N below 25 mg/100 g soil gives poor production; available N in the range 25–75 mg/100 g soil indicates average to high production. Organic carbon less than 0.5% is considered too low, 0.5–1.5% average, and 1.5–2.5% optimal (Table 1).

Nutrient Budget

Most Indian reservoirs are characterized by low values of phosphates and nitrates. Yet, many of them exhibit a high level of productivity. Permanent blooms of blue-green algae, in spite of low phosphate and nitrate values, have been reported in reservoirs such as Amaravathi. Such a situation is attributed to rapid utilization of the nutrients as well as to allochthonous inputs (Sreenivasan 1965; Franklin 1969; Ganapathi 1971; Mehrotra and Jhingran 1986). However, bottom accumulation of carbon dioxide, klinograde oxygen distribution, pH decrease in the bottom, and similar chemical indices convey the production potential more efficiently than nutrient levels (Sugunan 1986).

In deep-water ecosystems like reservoirs, nutrient recycling assumes enormous significance for sustained organic production. Observations in peninsular and northern Indian reservoirs point out that wind-caused turbulence and monsoon inflow facilitate the mixing of water masses and render the nutrients, locked in the tropholytic zone, available to trophogenic strata. In addition, northern Indian reservoirs that are monomictic, and conspicuous by thermal stratification in summer months, have the added advantage of water masses mixed by convection currents.

Silt turbidity, caused by ineffective soil-conservation measures, lowers productivity in many reservoirs in India. Poor light transmission lowers primary production. Although compensation depth in primary production assessment is reached at about 5 m for many southern Indian reservoirs, it is at only 2–2.5 m for reservoirs of the Damodar Valley Corporation, and Rihand in northern India.

Energy Transformation

Reservoirs in India differ with respect to incident light energy and its conversion into chemical energy (see Table 2). Only 0.2–0.68% of the incident solar energy is converted into chemical energy in these reservoirs. It is estimated that 41.7–65.2% of the energy fixed by the producers is actually stored; the rest is used for metabolic activities. The efficiency of energy flow through the food chain was found to differ drastically in managed and unmanaged reservoirs.

In Bhavanisagar, the efficiency of energy conversion from primary producer to fish was 0.28%, whereas in Rihand it was only 0.034%. This level of variation is attributed to the quantitative and qualitative variation in the species spectrum of the lakes. Two main pathways through which this primary chemical energy finds its

Table 2. Latitude-induced variations in availability of energy in selected Indian reservoirs.

Reservoir	Area at FSL[a] (ha)	Latitude (°N)	Available energy (J/m^2 per year)	
			Light	Chemical
Bhavanisagar	7 285	11°25'	891 × 10^4	36 740 (0.41%)
Nagarjunasagar	28 474	16°4'	858 × 10^4	24 932 (0.29%)
Rihand	46 538	24°	787 × 10^4	16 610 (0.20%)
Ramgarh	1 265	27°12'	766 × 10^4	34 459 (0.49%)
Gobindsagar	16 867	31°25'	720 × 10^4	48 936 (0.68%)

[a] FSL = full supply level.

way to fish are the grazing chain and the detritus chain (Natarajan and Pathak 1983). The contribution by both pathways to the total availability of energy is required to derive the species combination most suited to the ecosystem.

Observations made in these reservoirs revealed that the flow of energy is more through the detritus chain than the grazing chain. Only in the case of Rihand, where the fishery is almost entirely *Catla catla*, is the flow more through the grazing chain. Once the energy pathway is established, proper management can ensure a higher rate of energy harvest in the form of fish.

Biotic Communities

Plankton

Well-developed plankton cycles become established immediately after reservoirs are filled. A pattern of seasonal pulses occurs among the dominant species and produces blooms. Extensive data on spatiotemporal variations of plankton populations in Indian reservoirs depict, generally, two plankton pulses — one in February–June and the other in October–December. Whereas Myxophyceae (*Microcystis* spp) were observed to dominate in low-altitude reservoirs, they were replaced by dinoflagellates (*Ceratium* spp) in reservoirs, such as Gobindsagar, that are located at higher altitudes.

Macrobenthic Invertebrates

The sequence of dominance of benthic communities closely follows the fertility pattern. Preimpoundment debris offers a suitable habitat for benthic organisms. The sequence in benthos succession, especially chironomids, has been used to characterize habitat changes. The high shoreline development, variable slopes, and vegetation commonly associated with Indian reservoirs, support a rich assemblage of benthic organisms. Chironomids, gastropods, and annelids, in that order, generally dominate the scene. Maximum benthos density is usually observed at a depth of 4–10 m.

Of late, there has been an increasing tendency to consider the entire biotic community of a given reservoir and to interpret the observations through mathematical models (indices depicting species diversity, richness, similarity, etc.). A cumulative approach gives a better idea of the environment, and assists in developing a holistic management approach.

Periphyton

Among all the biotic communities in a reservoir, the periphyton have been least investigated. They form an important component of the food of browsers and contribute considerably to the total biomass of tropical reservoirs. This community as a whole reflects the productive capacity of the system and displays distinct responses to environmental stimuli.

Ichthyofauna

The rich fauna of Indian reservoirs is a consequence of the rich faunal diversity of the parent river systems. On average, a large reservoir harbours about 60 fish species (the number varies from 41 to 83) in addition to the crustacean and molluscan fauna. Of these species, at least 40 contribute to the commercial fishery to some extent. Among them, the fast-growing Gangetic carps, popularly known as Indian major carps, occupy a prominent place both as naturally occurring and stocked species. The broad categorization of the species is:

- The Indian major carps: *Labeo rohita*, *L. calbasu*, *Cirrhinus mrigala*, and *Catla catla*;
- The mahseers: *Tor tor*, *T. putitora*, and *T. khudree*;
- The minor carps including peninsular carps: *Cirrhinus cirrhosa*, *C. reba*, *Labeo fimbriatus*, *L. kontius*, *L. bata*, *Puntius sarana*, *P. dubius*, *P. carnaticus*, *P. kolus*, *P. dobsoni*, *P. hexagonolepis*, *P. chagunio*, *Schizothorax plagiostomus*, *Thynnichthyes sandkhol*, and *Osteobrama vigorsii*;
- Large catfishes: *Aorichthys aor*, *A. seenghala*, *Wallago attu*, *Pangasius pangasius*, *Silonia silondia*, and *S. childrentii*;
- Featherbacks: *Notopterus notopterus* and *N. chitala*;
- Air-breathing catfishes: *Heteropneustes fossilis* and *Clarias batrachus*;
- Murrels: *Channa marulius*, *C. striatus*, *C. punctatus*, and *C. gachua*;
- Weed fishes: *Ambassis nama*, *Esomus danrica*, *Aspidoparia morar*, *Amblypharyngodon mola*, *Puntius sophore*, *P. ticto*, *Oxygaster bacaila*, *Laubuca laubuca*, *Barilius barila*, *B. bola*, *Osteobrama cotio*, and *Gudusia chapra*;
- Exotic varieties: *Oreochromis mossambicus*, *Hypophthalmichthys molitrix*, *Cyprinus carpio specularis*, *C. carpio communis*, and *Gambusia affinis*.

Potential Yield, Catch, and Effort

A first approximation of fish-yield potential is of paramount importance to have an idea of the expected harvest before undertaking large-scale management measures. Several methods have been proposed for estimating fish production from lakes and reservoirs (Ryder 1965; Jenkins 1967; Gulland 1971; Sheldon et al. 1972; Oglesby 1977) with specific assumptions and variables. The morphoedaphic index (MEI), Jenkins' model, Gulland's model, and the trophodynamic model are important techniques for rapid assessment of lakes and reservoirs. Although the MEI approach has worked for large reservoirs, its validity has been doubted for shallow and small irrigation reservoirs (Jhingran 1989). The efficiency of the MEI in such waters reduced proportionally to the increase in the ratio of the lotic to the lentic character of the reservoir (Henderson et al. 1973).

Fish yields from Indian reservoirs during the period 1971–1979 have varied: 94.5–296.0 t (25.56–80.0 kg/ha) in Bhavanisagar; 32.3–190.0 t (1.75–10.0 kg/ha) in Nagarjunasagar; 147.3–328.8 t (4.89–10.91 kg/ha) in Rihand; 273.0–753.0 t (25.0–72.0 kg/ha) in Gobindsagar (Natarajan 1979). The yields obtained from Gobindsagar (76.5 kg/ha per year, 11 200 ha), Ukai (109 kg/ha per year, 36 523 ha), and Jaisamand (85 kg/ha per year, 8 120 ha) tempt one to set a target of more than 100 kg/ha per year even from large, deep reservoirs. Increases in fishing effort would contribute to an improved fish yield from these reservoirs. Although the methods of fishing have undergone considerable changes in recent years, they need improvement if the potential resources are to be fully exploited. The possibility of introducing active fishing gears to the reservoirs needs serious consideration.

Most of the native species have a wide distribution among the reservoirs. Mixes of species that have a variety of feeding habits ensure that all the niches are utilized. For most parts of the country, the three Indian major carps, *L. rohita*, *Catla catla*, and *Cirrhinus mrigala*, which are closer to the base of the food chain and command a lucrative market, are the ultimate choice. However, management is essential to maximize the yield within the given food spectrum, and to ensure a higher yield of the economic varieties.

Competition for food and space from weed fishes can be reduced by using trawl nets or seines of small mesh size. Seines, used in Tungabhadra reservoir in Karnataka, have been effective in checking and eradicating weed and trash fishes (David and Rajagopal 1969). Successful attempts have been made in Gandhisagar reservoir to introduce one- and two-boat bottom trawling to eradicate predators and trash fishes and to capture major carps and other commercially important species. Based on the trials, it was recommended that two-boat midwater trawling at 3–4 knots was more profitable for the exploitation of commercial species, whereas one- and two-boat bottom trawling at 2–3 knots was suitable for eradication of uneconomic species of fishes in reservoirs (Kartha and Rao 1990).

For successful management of the fisheries of large lakes and reservoirs, it is imperative that new whole-system models relating to yield assessment are developed. The methods of fish yield estimation at the community or subsystem levels currently in vogue require modification or refinement so that yields may be determined with greater precision. The recent management measures that have resulted in much higher levels of production in certain reservoirs are cause for optimism.

Pre- and Postimpoundment Measures

Preimpoundment surveys give firsthand knowledge about the possible species composition of the stream at the impounded stage. This information has been lacking for most of the Indian reservoirs. However, such surveys have been made mandatory for all reservoirs to be impounded in future. Preimpoundment surveys also provide information on: species in the river above the dam site and future stocking policies; breeding of fishes within the area of submergence and upstream to evaluate stocking; changes in the hydrobiological conditions of the area to be impounded; cleaning of the area of submergence of forest trees and other obstructions to facilitate the operation of fishing gear; provision of suitable fish passes for the migratory species, if any; and rehabilitation of displaced human settlements.

The survey forms the framework for the future fisheries development policies of the reservoirs. Postimpoundment measures can be broadly classified (Tripathi 1971) into the following:

- Stocking of mature brood fishes to build up the population of desired species, taking advantage of the initial fertility phase;
- Stocking of large fingerlings or yearlings (200–260 mm) so that their survival rate is higher (in many reservoirs, small fingerlings or fry are stocked and they serve more as food for predators than contribute to the fishery through artificial recruitment);
- During the first 5 years, only experimental fishing should be done to assess the stock and the success of stocked fishes in terms of growth and survival;
- The efficiency of gear and the catch composition of different gears should be estimated; and
- Qualitative and quantitative estimation of the food resources in the reservoir.

Because reservoir management strategies include stocking of fish, it will be necessary to establish hatchery facilities near the reservoir site or raise fingerlings in cages and net enclosures (Jhingran 1989).

Timber Clearance

Removal of timber from reservoir basins is still a disputed proposition (De Silva 1988). Some favour complete clearing, facilitating the fishing operation in the reservoir; some favour the clearance of only the large trees; whereas many advocate that a large area be left uncleared to dissipate wave action, retard erosion, reduce turbidity by flocculation of the colloidal clay, and provide substratum for a rich colonization of the periphyton (Bhukaswan 1980). Selective clearance of trees up to the draw-down limit has been favoured in India to facilitate operation of shore seines.

Extraneous Recruitment or Stocking

Natural recruitment can be improved by ecosystem management, or compensated for through stocking. Habitat management in Indian reservoirs is of limited feasibility. The ultimate choice is selective stocking. Reservoirs are amenable to stock manipulation or correction during the initial crucial years by selective stocking. Greater emphasis should be placed on species like Gangetic major carps that are in the short food chain. Lack of such measures would enable weed fishes of riverine ichthyofauna to take advantage of the available food resources and gain a foothold, and also provide an opportunity for catfishes to gain dominance. A case in point is Keetham reservoir, which, from a highly productive phase, turned into a stronghold of weed fishes (mainly *Gambusia chapra*) because a rational stocking policy was not adopted.

The stocking policy adopted so far in Indian reservoirs has generally been arbitrary. In many cases, no properly maintained stocking data are available.

Records show that the stocking density adopted for Uttar Pradesh (UP) and Madhya Pradesh varied from 371 to 495 fingerlings/ha in general, and was up to 4 115 fingerlings/ha in Keetham reservoir. Stocking policy seems to be guided by the availability of fish seed rather than by any rationale. This resulted in a substantial loss of valuable fish seed, and barely helped to achieve the desired goal. Despite arbitrary stocking, however, the catch has increased substantially in a few reservoirs. Recommendations regarding a rational stocking program in relation to productivity have been given by Jhingran and Natarajan (1969). Jhingran (1986, 1989) has also outlined stocking norms for small Indian reservoirs. Recommendations of the National Fish Seed Committee suggest a stocking rate of about 500 fingerlings/ha.

Stocking Rate

The stocking rate, S (number of fingerlings per hectare), can be calculated, based on the average growth rate of individual fish (G in kilograms) and the expected production (P in kilograms) by:

[1] $$S = (P/G) + L$$

where L = Loss due to mortality or escape (%).

Species Selection

The basic principles that should guide stocking policy and stock manipulation are:

- The food available per individual in the environment (both qualitative and quantitative);
- The individual growth rate and time to attain marketable size;
- The position in the food chain;
- The chances of survival of stocked seed (due to predatory pressure and environmental influences); and
- The extent of autostocking in the reservoir.

Impact of Exotic Fishes on Reservoir Fisheries

The introduction of exotic species in the country has always been viewed with a note of concern. These fishes, on entry into the open-water systems, may cause ecological distortions and adversely affect the productivity of indigenous species. The influence of three species (silver carp, common carp, and tilapia) has invited much debate. Although tilapia have been introduced deliberately to the reservoir systems, the presence of silver carp in a few reservoirs is a consequence of accidental entry. Nevertheless, the impact on native fauna has been serious. Figure 1 shows the trend of the fishery in Gobindsagar (Himachal Pradesh) influenced by an accidental entry of 34 silver carp from an adjoining farm. In 17 years, the species multiplied to contribute 79.8% of the 785 t of fishes landed from the reservoir in 1988/89 (Kumar 1990). The performance of the species in Kulgarhi reservoir (Madhya Pradesh) and Getalsud reservoir (Bihar) is remarkable. The fish registered a growth of 4–5 kg in 1.5–2 years.

The experiments with tilapia are also discouraging. *Oreochromis mossambicus*,

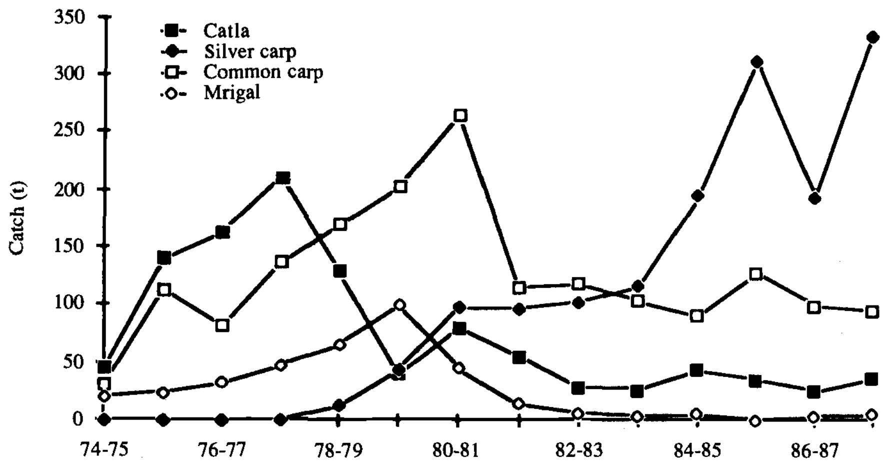

Fig. 1. Changes in the catch structure of Gobindsagar after the introduction of silver carp.

introduced to some reservoirs in southern India, proved to be a menace. In Vaigai reservoir (Tamil Nadu), it replaced all the species including Indian major carps. In 1964/65, the species contributed 99% of the total catch. Amaravathi, Sathanur, and Powai lakes are other places where tilapia seriously altered the species spectrum of the native fauna, eventually bringing down production. However, tilapia has yet to gain a stronghold in northern Indian reservoirs.

The effect of common carp was not as discouraging, although it displaced the native snow trout from Dal Lake in Kashmir. So far, the grass carp has not made a dent in the open waters, probably because of its feeding and breeding restrictions. The larvivorous species *Gambusia* nearly caused the collapse of local varieties in Ooty Lake due to its habit of devouring their eggs and embryos.

An arbitrary introduction of an exotic variety is no longer permitted in Indian waters. Any proposal for such an introduction is brought to an expert committee that evaluates the proposal. If required, the species would be subjected to rigorous experimentation to ascertain its possible effect on the native fish population.

Fish Population Dynamics and Stock Assessment

The fishery exploitation policies for reservoirs are increasingly influenced by mathematical models and assumptions of stock assessment. There have been some difficulties in practicing the stock-assessment models that operate for multispecies fisheries. Hence, these are recognized more in words than in practice as Gulland (1983) suggested for fisheries around the world. Most of the reservoirs in India suffer from varying degrees of underexploitation, and improvement in yield has been invariably obtained by increasing the effort. In Gobindsagar reservoir, an increase in mesh size from the existing <65 mm to 100–180 mm, and a 120% increase in fishing effort, resulted in production increasing from 273 t in 1975 to 827 t in 1978.

Parasites and Diseases

Ligulids (Cestode) have a wide distribution in Indian reservoirs and the occurrence of pleurocercoid larvae of *Ligula* sp. has been reported in *Catla catla*, *Labeo rohita*, *L. calbasu*, and *Rasbora daniconius* (Gopalakrishnan 1964). The infestation comes mainly from birds. Major carps and catfishes have also been found to be infested with metacercaria of *Isoparorchis* sp. Recent outbreaks of the epizootic ulcerative syndrome in India has made the reservoir fishes vulnerable to this dreaded disease. There is an urgent need to undertake necessary prophylactic measures to protect the fingerlings that will be introduced into the reservoir.

Anthropogenic Impact

Reservoir shores form an ideal site for installing thermal power plants and setting up a variety of industries. Although strict regulations against environmental abuse do exist, they are often violated. Mass death of fish has been observed repeatedly in Rihand reservoir and considerable concentrations of heavy metals were detected in water, sediment, and aquatic plants in reservoirs such as Byramangala near Bangalore. The fly-ash from thermal plants, as observed in Rihand, caused destruction of the benthic fauna and brought about a shift in the fishing grounds due to the blanket effect. Because reservoirs are lentic systems that retain limited quantities of water during the summer, they are more vulnerable to polluting agents than fluviatile systems. Reservoir waters, in general, are low to moderately hard due to low buffering capacity and are more susceptible to pollution from heavy metals, pesticides, and other pollutants. Treatment of waste should form an integral part of all industrial planning.

Fish Passes

Reservoirs without fish passes often obstruct the path of migratory fishes, whether catadromous, anadromous, or fish that migrate entirely within the freshwater stretch. Even where fish passes are available, as in case of Farakka barrage, the passes are not functional due to faulty design. Migratory fish can be on relatively inflexible energy and time budgets and may not tolerate delays in migration (Northcote and Larkin 1987). Consequently, the stock of the species in the entire parent stream could be severely affected. The classic example is the hilsa stock in the Ganga, above the Farakka barrage, which was reduced to insignificance after the barrage was commissioned.

Small Reservoirs

The dependence of Indian agriculture on the southwest monsoon and its consequent vulnerability have necessitated maximum utilization of the country's surface and groundwater resources, which are estimated at 66.5 and 27.5 million ha, respectively. In contrast to the large multipurpose reservoirs, the small irrigation reservoirs, created on small intermittent water courses, serve to trap the surface runoff for use during irrigation. Experience has revealed that these water bodies offer immense potential for fish husbandry through extensive aquaculture.

No clear-cut classification of reservoirs into categories (small, medium, and

Table 3. Small reservoirs compared with large reservoirs.

Small reservoirs	Large reservoirs
(1) Single-purpose reservoirs mostly for minor irrigation.	(1) Multi-purpose reservoirs for flood-control, hydroelectric generation, and large-scale irrigation.
(2) Dams neither elaborate nor very expensive. Built of earth, stone, masonry work on small seasonal streams.	(2) Dams elaborate, built with precise engineering skill on perennial or long seasonal rivers. Built of cement, concrete, or stone.
(3) Shallower, biologically more productive per unit area. Aquatic weeds commonly observed in perennial reservoirs but absent or scanty in seasonal ones.	(3) Deep, biologically less productive per unit area. Usually free of aquatic weeds. Subjected to heavy drawdowns.
(4) May dry up completely in summer. Notable changes in the water regimen.	(4) Do not dry up completely. Changes in water regimen not so pronounced. Maintain dead storage level.
(5) Sheltered areas absent.	(5) Sheltered areas by way of embayments, coves, etc. present.
(6) Shoreline not very irregular. Littoral areas mostly gradually sloping.	(6) Shore line more irregular. Littoral areas mostly steep.
(7) Oxygen mostly derived from photosynthesis in the shallows, nonstratified reservoirs lacking significant wave action.	(7) Although photosynthesis is a source of DO the process is confined to a certain region delimited by the vertical range of transmission of light (euphotic zone). O_2 also derived from significant wave action.
(8) Provided with concrete or stone spillway, the type and size of its structure depending on the runoff water handled.	(8) Provided with much more complex engineering devices.
(9) Breeding of major carps, if any, in perennial reservoirs above the spillway.	(9) Breeding mostly observed in the headwaters or in other suitable areas of the reservoir.
(10) Can be subjected to experimental manipulations for testing various ecosystem responses to environmental modifications.	(10) Cannot be subjected to experimental manipulations.

(continued)

Table 3 concluded.

Small reservoirs	Large reservoirs
(11) Trophic depression phase can be avoided through chemical treatment and draining and cycle of fish production can be repeated as often as the reservoir is drained.	(11) Trophic depression phase sets in.
(12) The annual flooding of such reservoirs during rainy season may be compared with overflowing flood plains; leads to higher growth and survival.	(12) Nutrients are lost and get locked up in bottom sediments. Reduction in benthos also occurs due to rapid sedimentation.
(13) Through complete fishing or overfishing in such seasonal reservoirs, no brood stock is left to contribute to succeeding year's fishery through natural recruitment. The fish population has to be built up solely through regular stocking. There is thus a direct relationship between stocking rate and catch per unit of effort.	(13) In contrast, prominent annual fluctuations in recruitment occur and balancing of stock number against natural mortality requires excessive number of fingerlings in such large reservoirs. Their capture requires effective exploitation techniques.

large) has been made. The Fish Seed Committee of the Government of India called all water bodies "reservoirs" if they were more than 200 ha. David et al. (1974) classified the water sheets of Karnataka state on an area basis, and designated impoundments above 500 ha as "reservoirs" and those under 500 ha as "irrigation tanks." In the USSR, reservoirs up to 10 000 ha are assigned to the small category; whereas, in the USA, they may range from 0.1 ha to several hectares (Bennett 1970). In India, the following classification is being adopted: reservoirs above 5 000 ha are large; those between 1 000 and 5 000 ha are medium; and those below 1 000 ha are small (Sharma 1990). The broad distinguishing features of large and small reservoirs are summarized in Table 3.

Past and Present Approaches

Because of the urgent need to enhance inland fish production in the country, emphasis is being placed on a short-term experimental management approach toward reservoir fisheries development. This approach is based on: collection of data on key limnochemical parameters of water and soil; quantitative biology; and efficient exploitation techniques that would provide a clue to the productive potential of the ecosystem and would be helpful in setting valid targets of fish production from such water bodies (Mehrotra and Jhingran 1986). Jhingran (1986) has given necessary guidelines toward formulating fisheries-development strategies for reservoirs.

Good responses to these management options can be seen in many smaller

Indian reservoirs that have raised their yield to 140–200 kg/ha per year. Keetham, a small reservoir of 259 ha in UP, has produced a yield of 530 kg/ha. Subsequently, small reservoirs — such as Loni in Madhya Pradesh (MP), DVC reservoirs in Bhihar, Gulariya and Bachhra in UP, and Aliyar in Tamil Nadu — were investigated to test the validity of the approach. Results obtained from some of these reservoirs are given in Table 4.

Stocking serves as a useful tool for management of small reservoirs. With the drastically diminished summer water level, such reservoirs are liable to be fished heavily and no broodstock is left to contribute to the next year's fishery. Therefore, catch from such water bodies is totally dependent on stocking. Optimum stocking density in small reservoirs is based on the potential yield and depends on the basic productivity levels and the individual growth of the desired species, giving allowance for natural mortality and escape of fingerlings through the irrigation canal and the spillways.

The flooding of small reservoirs, which dry up completely during summer season, has been compared by some authors to the annual flooding of flood plains. This helps release more nutrients in the reservoir and results in increased food production through decomposition of organic matter. In some states, the exposed areas of such reservoirs are used for leguminous crops, which help to mineralize the soil and lead to higher growth and survival of the fish in reservoirs. The absence of predators and the biologically higher production of such reservoirs allow stocking of advanced fry (40–150 mm) early in the season, instead of fingerlings, to give a maximum grow-out period.

Integrated Development Strategy

In keeping with the need for rapid assessment of the country's small reservoir resources, an inventory of such ecosystems along with estimates of their potential yields has been suggested for planning purposes. This can be further categorized into those reservoirs that: first, are best developed for capture fisheries; second, have significant potential for fish culture; and, third, are intermediate in size and potential yield. The reservoirs may then be substratified in terms of priority, based on their basic productivity levels, geographic location, market vicinity, and demand.

Because major carps breed in some small reservoirs (like Loni in MP) above the spillway, there is heavy escape of fingerlings and adults through the irrigation canals. Development of fisheries in such water bodies, therefore, requires suitable screening of the spillway and the canal mouth. Such measures, adopted in some of

Table 4. Production trends in scientifically managed small reservoirs in India.

Reservoir	Area (ha)	Yield (kg/ha): Before scientific management	Yield (kg/ha): After scientific management
Gulariya, Uttar Pradesh	150	33	100
Bachhra, Uttar Pradesh	140	—[a]	139
Aliyar, Tamil Nadu	646	27	202

[a] New reservoir.

the reservoirs in MP state, have increased the fish yield considerably. To minimize escape through the spillway and canals, it would be an economic proposition to have an annual cropping policy. The reservoirs would be stocked during September–October and harvested by the end of June, giving an 8- to 10-month grow-out period.

Aquaculture in small reservoirs can play an important role in integrated rural development because it can be combined profitably with livestock. The exposed areas of the reservoirs can be utilized for farming of leguminous crops, which also add to the fertility of the soil. Such schemes promise to increase fish production and rural earnings, and make a significant contribution to the nutritional requirements of the rural community.

General Considerations

The management of reservoirs for optimum yield and the evolution of a common approach for a given category of reservoirs have posed a major challenge to fishery scientists. The multiplicity of factors influencing the productivity of reservoirs necessitates a multidisciplinary approach.

In almost all states of India, some form of fishery regulation is being followed. These regulations basically pertain to the minimum mesh size of the gear, closed seasons for fishing during the carp breeding season, prohibition of illegal fishing, and the number of fishing units, crafts, and gear. The regulations vary from state to state, and even from reservoir to reservoir, to suit local situations. Although most of the regulations are backed by biological reasoning, some of them are conspicuously based on economic considerations.

Fishing in reservoirs is a predominantly capture-based activity. The renewable nature of the fishery resource, coupled with biological and environmental features, offers challenging frontiers to our management capabilities to determine commercial levels of exploitation. The fishery potential of reservoirs is largely underexploited. Social problems arising from exploitation by fish dealers are the biggest impediments in improving the lot of those who fish. An investment level of 632 700 INR (1 USD = 17 INR) in Bhavanisagar, Tamil Nadu (3 695 ha), affords gainful employment to 76 people at an annual income level of 8 175 INR/person (Paul and Sugunan 1983). However, the exploitation by dealers was observed in Ramgarh reservoir, Rajasthan (1 260 ha), where a net income of 582 743 INR could have accrued to 48 fishing people, if the reservoir had been managed by a cooperative (Jhingran 1989). Even after leaving a margin of 10% for royalties to the state government, the people would have received more than three times what the contractor paid.

Cooperative societies have a great role to play in reservoir fisheries in India. Policy instruments, such as choice of reservoirs, leasing system, stock monitoring, and fishing efforts backed by efficient postharvest machinery, can go a long way to improving the socioeconomic status of the people fishing in the reservoirs.

Research has contributed to the new approach to management of reservoir fisheries in the country. The efforts made so far have identified and narrowed the gaps in our knowledge of complex reservoir ecosystems. The approach followed depends on the priority the country places on enhancing fish production.

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Present Status and Prospects for Reservoir Fisheries in China

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The reservoir resources of China are evaluated and their fisheries are discussed. The technological measures that have been used to maintain a high level of fish production are reviewed. The research that will be needed to achieve the targeted development of the reservoir fisheries in the next decade is highlighted.

It is estimated that there are 86 881 reservoirs in the People's Republic of China. Of these, 328 (0.4%) are classified as large (capacity >10 million m^3); 2 333 (2.7%) as medium (capacity 1–10 million m^3); 14 232 (16.4%) as small (type a) (capacity 0.1–1 million m^3); and 69 988 (80.5%) as small (type b) (capacity <100 000 m^3) (Chen 1987). The area of water surface amenable to fish farming (AWFF) in all reservoirs is 2 million ha, constituting 40% of the nation's freshwater fish farming area. This is 1.5 times the area of ponds, and 130 000 ha more than the fish-farming area of all the lakes in China.

The administrative management of reservoir fisheries was assigned to the Department of Water Resources in 1979. Since then, the use of water for fish farming and agriculture has been coordinated and this has resulted in high fish production. The overall fish production rose from 112 000 t in 1980 to 308 700 t in 1988, and the average production per hectare rose from 88.4 kg to 214.1 kg (Table 1). Advanced high-output models manifested themselves throughout the country: the Dahuofang reservoir in Liaoning Province (with 5 333 ha of AWFF), which produced only 120 t in 1979, reached 1 625 t in 1987, with the yield exceeding 300 kg/ha; the Qinshan reservoir in Zhejiang Province (AWFF 533 ha) had a fish yield of 750 kg/ha (Table 2).

Reservoir Fisheries Research in China

Limnological Research

After impoundment, fish production in a reservoir generally reaches its peak in 3–5 years, and then stabilizes. The Tieshan reservoir in Hunan Province was

Table 1. Reservoir area and fish production in China, 1980–1988.

Year	Area (10^3 ha)	Production	
		Total (10^3 t)	Yield (kg/ha)
1980	1 267	112	88.4
1981	1 281	119	92.9
1982	1 299	133	102.4
1983	1 298	149.5	115.2
1984	1 335	175	131.1
1985	1 376	206	149.7
1986	1 402	236	168.3
1987	1 430	278.6	194.8
1988	1 442	308.7	214.1

Source: Yu (1989).

Table 2. Fish production of some large- and medium-sized reservoirs in China.

Reservoir	Province	Area (ha)	Production (kg/ha)	Year
Xinanjiang	Zhejiang	40 000	94.5	1986
Hedi	Guangdong	6 733	85.5	1980–1986
Dahuofang	Liaoning	5 333	304.7	1987
Minshan	Hubei	667	375	1984–1986
Huchenggang	Zhejiang	576	570	1983–1985
Qinshan	Zhejiang	533	750	1978–1987
Modaohu	Guangdong	80	750	1980–1987
Zishanchun	Hunan	64	1 459.5	1984–1986

Source: Yu (1989).

completed in 1981 (AWFF of 2 667 ha). In 1983, fish production exceeded 500 t, and the economic efficiency was fairly good.

In China, two approaches are adopted to increase fish production. In one approach, the factor or factors that are correlated with the growth of fish are determined, then the reservoirs are separated into different types and different indices of fish productivity are instituted for each type. This is designated as the method of type differentiation. In the other approach, the quantity of forage organisms is determined and fish productivity in terms of the production/biomass (P/B) index, the permissible utilization rate, and the food conversion ratio is computed. This is designated as the method of determination and calculation.

For more than 20 years, Chinese hydrobiologists have been engaged in the study of the trophic status of reservoirs. On the basis of the condition of the drainage area (the watershed) and the inundated area, the morphology of the reservoir, the average depth of water, hydrological features, transparency, pH, quantity of plankton, primary productivity, and the production cycle of silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*). Lin (1986), divided the reservoirs into: eutrophic (fish productivity >375 kg/ha); ordinary or median (fish productivity 150–375 kg/ha); and oligotrophic (fish productivity <150 kg/ha).

The P/B index for different geographic regions and the allowable utilization rate in different reservoirs vary. He and Li (1983) calculated the productivity of plankton-eating fishes in Qinghe reservoir, Liaoning Province, and concluded that it could yield 450 kg/ha. Xie Z. (1989) investigated the biomass of the benthic invertebrates of the same reservoir, and derived a fish productivity of 216 kg/ha. Wang et al. (1989), on the basis of primary productivity, estimated the fish productivity of Donghu Lake, Wuhan Province, to be:

For silver carp:

[1] $FH = 0.0466\,Hy \times PG$

For the bighead carp:

[2] $FA = 0.0804\,Ar \times PG$

where Hy and Ar = stocking ratios of silver carp and bighead carp, respectively; and PG is the gross productivity of phytoplankton in the water column (g O_2/m^2). It is difficult, however, to develop a single index for predicting fish production.

A plan to survey all fishery resources in reservoirs has been drawn up but not yet put into action. Guidelines for extensive surveys have been established in conjunction with district fishery-planning work, for instance, in the provinces of Liaoning, Shangdong, Sichuan, Heilongjiang, and Fujian. The intent is to develop a system to differentiate the various types of reservoirs in terms of their fishery potential. The system will be established when the nationwide survey of the potential fish production in reservoirs is completed.

Fish Population Studies

After impoundment, there are a series of profound changes in hydrological and biological conditions. Lacustrine fishes find the new conditions favourable because of improvements in habitat, reproduction, and forage supply; riverine fishes, however, migrate upstream of the reservoir. Because of the obstruction of the path of migration, migratory fishes vanish gradually (Yu et al. 1981; Li and Xu 1988). Chen et al. (1978) studied the regularity of succession of the predatory fish species in the reservoirs at the middle and lower reaches of the Chang Jiang River. They found that the populations of predatory fishes show a phenomenon of succession.

To promote the efficiency of fishing and fencing, studies were made on the distribution of fish populations in reservoirs. Zhu (1984) disclosed that the distribution of the mud carp (*Cirrhina moletorella*) in reservoirs varies markedly with changes in the biotic environment and depth. Cheng (1983) studied the activity of silver and bighead carps in reservoirs, including their aggregating ability, and discussed the activities of shoals of carps and how this behaviour can be used for fishing.

Technical Measures to Increase Fish Production

Clearance of Reservoirs

For long-term benefits, the bottom is cleared before a reservoir is impounded (Li and Xu 1988). Chen (1985a, b) argues that the fish species, food habits, and fishing methods should be analyzed to justify the necessity of such clearance. For instance, when fish farming is confined to cages, when only stake nets are used for fishing, or when electric fishing is employed, there is little need for such clearance. However, if beach seines are the principal gear, substratum clearance is indispensable. Xie (1989), envisaging the prospect of reservoir fisheries and considering the demand for fishing and fish culture, suggested substratum clearance for the Ankang reservoir, Shanxi Province.

Stocking

One of the main features of Chinese reservoir fisheries is the artificial stocking of silver carp and bighead carp. Stocking is influenced by the biological features and production of these species, and socioeconomic level of the country. Chen (1982) considered that the effect of stocking one bighead carp fingerling of average length 14.8 cm was equivalent to stocking 3.2 bighead fingerlings of total length 10–13 cm or 21 bighead fingerlings <10 cm. Li (1983), however, maintained that the size for stocking is influenced by many factors. As a rule, a size norm set at 13.3 cm in total length seems adequate. For newly constructed reservoirs, where there are few predatory fish, fingerlings 8.3–10 cm in total length may be used for stocking. Decisions on stocking density and the proportions between stocked species are made mainly through experience gained in previous years.

Hypomesus olidus (a smelt) is an example of the successful transplant of a northern cold-water fish. Up to the spring of 1989, 4.9 billion fertilized eggs of this fish were transplanted into 95 reservoirs and lakes (total water surface 110 000 ha) in 17 provinces. This fish could be recaptured from 68 water bodies and, in 22 of them, the species has begun to contribute to fish production. In 1988, transplanted *Hypomesus* yielded 200 t (Xie Y. 1989). The transplant of fish of the Nase family (Xenocypridae) has been accepted by more and more people; reservoirs, after transplantation, can generally increase their production by 7.5–15 kg/ha (Chen 1985a, b).

Cage culture of silver and bighead carps is undertaken to eliminate escape of the stocked fish and predation. Chen and Lin (1982) reviewed the technical and economic aspect of nonfeeding cage culture and concluded that, at the present level of technology and management, the economic benefit of cage culture was equal to stocking of the reservoir when the economic benefit of stocking reaches 3.5. They considered cage culture to be better if the economic benefit of the stocking was lower than 3.5. Tian (1986) studied the desirable water depth for nonfeeding, enclosed cages in large-sized reservoirs based on the vertical distribution of plankton. Shi and Wang (1988) studied the total area that could be used for cages of silver and bighead carps. The number of cages that could be installed in a reservoir was limited. For example, in Fuziling reservoir, Anhui Province, 8 ha of cages were installed in 1987 (equivalent to 0.6–0.7% of the total AWFF in the reservoir) and the average weight at harvesting dropped noticeably. The natural forage resources in the reservoirs of Dabieshan district are comparatively rich; the average production for nonfeeding cages reaches 4–5 kg/m^2 (Chen 1985a, b). Because of the good water quality of the reservoir, cages have been successful for culturing sizable fish seedlings in large numbers to meet local needs for mass stocking.

In a balanced reservoir ecosystem, fish production is restricted by the food-supply capacity of the natural forage organisms. In the Dabieshan region, where forage is comparatively rich, production of silver and bighead carps in the large-sized reservoirs generally does not exceed 350 kg/ha. When the production of detritus feeders is included, fish production can reach 400–500 kg/ha (Chen 1985a, b).

In China, the principal way of increasing forage organisms in reservoirs is regular input of allochthonous nutrient material, including the application of fertilizers, application of feeds in cage culture, and integrated farming. The transplant of forage organisms has been attempted in a few reservoirs, e.g., Xinanjiang reservoir and the Dongfeng reservoir in Zhejiang Province.

Chemical fertilizers are used to supplement manure and to increase the forage available for the filter-feeding fish species, thus sustaining a higher stocking density and a higher fish yield. In those fish farms where fertilizing (or manuring) is practiced, the production is generally 450–750 kg/ha, and the fertilizer coefficient is 1.5–2.0 (Li 1989). In Sixin reservoir (AWFF 16.7 ha), Liaoning Province, the application of chemical fertilizers supplemented by manuring increased yield from 360 to 958.5 kg/ha, and the economic benefit was fairly high (Chen 1986). The most extensive application of fertilizers has been in Baiguohe reservoir (AWFF 166.3 ha), Hubei Province, where production reached 505.5 kg/ha (Chen et al. 1986) (Table 3). Problems such as the selection and combination of various kinds of fertilizers, the intensity and frequency for fertilization, and the best species and combinations of fish species still await systematic study.

The main species that are fed in cages are the common carp and the tilapias (*Tilapia* spp). When pellet feeds (formulated feeds) with fishmeal and soybean residue are used as the chief protein source, the food conversion ratio is about 2. Large-scale production averaged 75 kg/m^2 (Li 1989). In Dahuofang reservoir, Liaoning Province, 1 350 m^2 of cages for common carp, and 325 m^2 for *Tilapia nilotica* yielded 139.9 kg/m^2 (conversion rate 2.16) and 72.5 kg/m^2 (conversion rate 1.69), respectively (Liu et al. 1988) (Table 4). Because of the high return, cage culture has developed quickly. The total area for cage farming with feeding in the whole country (except Taiwan) has reached 400 000 m^2 (Li 1989). Fish farming in cages with feeding has surmounted the technical difficulties. However, constraints for its further development are economic — such as capital for production, costs, and marketing). In the southern part of China, experiments on cage culture of the grass carp (*Ctenopharyngodon idellus*) and the blunt snout bream (*Megalobrama amblycephala*) have produced satisfactory results (Yang and Xu 1987; Yang and Zhao 1988).

Table 3. Fish yields of some fertilized Chinese reservoirs.

Reservoir	Province	AWFF (ha)	Fish yield (kg/ha) Pre-fertilizer	Fish yield (kg/ha) Post-fertilizer	Fertilizer (kg/ha per year)	Year
Baiguohe	Hubei	166.3	210	505.5	525	1985
Lamazhang	Liaoning	133	—	472.5	297	1985–1986
Liangjiawan	Shanxi	84	61.5	289.5	480	1985–1986
Taqiaowan	Xinjiang	60	219	975	120	1987
Sixin	Liaoning	16.7	360	958.5	360	1982–1983

Source: Yu (1989).
Note: AWFF = area of water surface amenable to fish farming.

Table 4. Fish yields from cage farming of common carp in some Chinese reservoirs.

Reservoir	Province	Area of cages (m^2)	Average production (kg/m^2)	FCR	Year
Haizi	Beijing	3 330	97.6	—	1987
Dahuofang	Liaoning	1 350	139.9	2.16	1987
Cuntangkou	Sichuan	1 140	114.7	2.12	1987
Xinxinshao	Jilin	400	75.5	2.16	1986
Nanshahe	Shanxi	350	74.3	2.36	1988

Source: Yu (1989).
Note: FCR = feed convertion rate.

Recently, in a number of small reservoirs, integration of fisheries with animal husbandry, agriculture, or industry has commenced. Lu (1988) studied the comprehensive farming of grass, poultry, livestock, fish, and mussels in three small reservoirs (type b) and obtained a fish yield of 7 963 kg/ha, with remarkable economic benefits. Small reservoirs are very likely to become highly productive water bodies, second only to ponds.

In China, fencing of the reservoir spillway to prevent escape is given priority. There are two forms of fencing in common use: nets and screens. Experiments using large bar-nets, which can withstand flood flows, have been started, but no extension work has been done because the key problem of defouling the net is yet to be solved. In certain middle- and small-sized reservoirs, electric fish screens have been placed in front of the spillway. However, for large-sized reservoirs, the efficacy of electric fish screens needs further investigation.

Trash fish are considered to be competitors for fish food for economic fishes. In the past, predatory fishes were introduced to prey upon these trash fish or their fishing intensity was increased. With the growth of the fishery and the change in our dietary habits, the control and use of trash fish has attracted the attention of many reservoir administrators. In Nanchenzi reservoir (AWFF 533 ha), Liaoning Province, 40 t of trash fish (30% of total catch) were caught in 1985. In 1986, 30 t of trash fish were landed (Li 1988).

The control of predatory fish is important in those reservoirs where commercial fishery plays an important role, and particularly in reservoirs that are stocked. Fish production in Fuqiaohe reservoir, Hubei Province, reached 845 t in 1966, but dropped to only 49.5 t in 1975 because of the damage done by the predatory fish, *Elopichthys bambusa*. When this fish was wiped out, the fish yield of this reservoir recovered rapidly to 300 t (Chen et al. 1978). The principal measures for control of predatory fish consist of the destruction of spawning grounds, poisoning, and fishing. The adults of lesser-sized predatory fish (*Erythroculter dabryi* and *Culter erythropterus*) can devour fingerlings (5–6 cm) of silver carp and bighead carp. However, if the reservoir is stocked with fingerlings >13 cm, these two predatory species can only feed on trash fish, and thus play a role in suppressing the competitors of the stocked fish (Li and Xu 1988).

Some predatory fish, such as the mandarin fish (*Siniperca chuatsi*), are noted for their flesh quality. The biology of this fish has been studied by Liu et al. (1989), who have succeeded in farming the species.

When the natural spawning ground is disturbed, or when the water level cannot be regulated to meet spawning requirements, the installation of "fish nests" made from the outer covering of the palm stem, or from aquatic weeds, or the construction of an artificial spawning ground, can improve the reproduction of reservoir fishes. The chief aim when installing an artificial "fish nest" is to provide a substrate for the eggs of those fish that deposit their eggs on submerged vegetation. In Shanghongdian reservoir (AWFF 4 000 ha), Anhui Province, artificial fish nests were installed to favour the spawning of the crucian carp (*Carassius auratus*). Fish yields increased by 80 t and the ratio of input to output was 1:5. The economic benefits are obvious (Zu 1990). In Tonghuan reservoir (AWFF 100 ha), Hunan Province, an artificial concrete spawning ground was constructed in 1983 for the propagation of *Xenocypris microlepis*. Up to 1986, 30 million fry had been hatched (Deng and Zhou 1987).

Coves are usually established in a reservoir by building earthen dams or by net-fencing, or a combination of a dam and fencing. Coves provide a nursery for fish seedlings or for the rearing of market-sized fish. This practice is advantageous and is known as cove fish-culture. The Xinfushan reservoir, Jiangsu Province, has 8 ha of dammed coves, which yielded 4 722 kg/ha in 1986, and 7 875 kg/ha in 1987 (Water Conservancy Department of Jiangsu Province 1988) (Table 5). Cove fish-culture by damming affects the storage capacity of the reservoir and presents certain engineering management problems. Cove fish-culture by net-fencing began in the 1970s, but success has been meagre.

Large-scale fishing in Chinese reservoirs is generally done in winter. During the remaining seasons, only small fishing gears are used for the capture of trash fish. The minimum fishable size of bighead and silver carps is 1 kg. The total quantity to be caught is determined by experience, and fishing activities are regulated accordingly. After the success of the mass capture of silver and bighead carps in Xinanjiang reservoir, Zhejiang Province, by the joint operation of the driving net, the bar net, the gill net, and the stake net, this method of joint fishing has met with widespread acceptance and application in reservoir fisheries.

Application of this method in Fuqiahoe reservoir, Hubei Province, resulted in a catch of 270 t of fish in a single haul in 1980. The problem of catching fish in the

Table 5. Fish production in coves of various reservoirs.

Reservoir	Province	Cove area (ha)	Production (kg/ha): Fish seedlings	Production (kg/ha): Market fish	Year
Xinfushan[a]	Jiangsu	8	—	7 875	1987
Fuqiaohe, Qianhe[a]	Hubei	6.7	3 172.5	—	1984
Danjiangkou, Fenghuangshan[b]	Hubei	5.3	—	7 579	1986
Shahezi No. 2[a]	Jilin	3.2	5 085	—	1982
Zhonglupu[a]	Hunan	0.9	—	7 695	1985

Source: Yu (1989).
[a] Dammed cove.
[b] Cove with net-fencing.

upper and middle strata has been solved. Several different gears and fishing methods are used for benthic fish, but few of them have proven to be effective. The Zhejiang Provincial Freshwater Fisheries Research Institute has used a trans-strata trammel net to catch common carp. The maximum daily catch of this fish during the spawning season was 87 kg for a single boat, and in the autumn the maximum catch per day was 68 kg. The effect of fishing with this net seems satisfactory (Cheng 1982). The use of stake nets (for capturing and fencing), such as the net-weir, net-cage weir, the fixed-net cage, seems quite effective for the capture of both benthic fishes and pelagic predatory fishes.

These reservoirs represent individual cases of increased production. Because 99.6% of the medium- and small-sized reservoirs tend to be found in groups, fishery exploitation of these reservoir assemblages on the principle of system engineering should bring about the so-called magnitude effect (Chen 1987). Reservoir assemblage fisheries would favour the integrated organization of fish-seedling production, fishing for commercial fish, and the sale of fish products. This would mean that inputs could be mobilized more effectively and the goal of increasing fishery production and its economic benefits could be realized in a relatively short time. Experiments with fisheries exploitation in reservoir assemblages for 83 medium- and small-sized reservoirs (in seven counties and one city in Hubei Province) in 1988 produced 1 960 t of market fish, with an average production of 392.1 kg/ha (a 40% increase compared with 1987). Among them, the nine reservoirs in Xiangyang county (AWFF 913 ha) doubled their combined 1987 production. Although research on reservoir assemblage fisheries in China has just started, it does indicate a trend for the development of reservoir fisheries.

Conclusion

China is a developing country with a large population but limited arable land. Pond culture, the mainstay of freshwater aquaculture, has developed to the stage where further substantial expansion in area would be difficult. There is potential for enhancement of the unit-area productivity of ponds, but the demand for inputs per unit area is great and is a constraint on further development of pond culture. The development of lake fisheries is also restricted by constraints such as the silting and aging of many lakes. In contrast, with the continual construction of water-conservation projects, reservoirs for fish culture will increase progressively, and reservoir fishery will become the major enterprise for increasing freshwater fishery production.

Reservoir fisheries in China is in its infancy. Although the area for reservoir fish culture constitutes 40% of the total area for freshwater aquaculture of the nation, its production is less than 10% of the national total. Fish production per hectare is less than 50% that of lake fishery, and only 10% of pond culture. According to a preliminary computation (Wang et al. 1989), the potential for reservoir fishery production in China is 3–4 million t, i.e., 10–13 times the fish production in 1988. With the implementation of appropriate technical measures and with more intensive management, reservoir fish-production in China is expected to reach 650 000–700 000 t/year in the near future.

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Types and Efficiencies of Reservoir Fisheries in China

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Reservoir fisheries development has reached an unprecedented stage in China. In 1988, the average fish yield was 215 kg/ha for 1 441 300 ha of cultured reservoirs. A major achievement has been the development of different utilization types: open fisheries; extensive stocking; semi-intensive and intensive culture; a combination of extensive and intensive culture; and integrated farming systems. The technology must be modified to suit local conditions and the fish yields vary depending on the type of culture. Extensive stocking is a major part of reservoir fisheries, but intensive culture is increasing.

Traditional freshwater fish culture is concentrated in the basins of the large lakes and river systems. The Changjiang basin and the Zhujiang basin are the two largest in China. Reservoir fisheries, in contrast, are located mostly in mountain areas (which account for 70% of China). Here, there is little fish culture and a limited supply of fresh fish. Therefore, the development of reservoir fisheries is important for the production of animal protein, particularly in rural areas.

Reservoirs are artificial ecosystems characterized by the existence of both lentic and lotic components, wide seasonal fluctuations of water level, and high water-exchange coefficients. Reservoir fish-production is influenced by climatic, edaphic, and morphometric features, by the ichthyofauna, and by human management. In the 1980s, reservoir fisheries in China developed rapidly (Fig. 1).

Types of Reservoir Fisheries

The reservoir fisheries systems being used in China can be grouped into five categories: open fisheries, extensive stocking, semi-intensive and intensive culture, combination of extensive and intensive culture, and integrated fish farming.

Open Fisheries

In open fisheries, the primary approach is to enhance naturally occurring fish resources; stocking of fingerlings is secondary. This type of system is most suitable

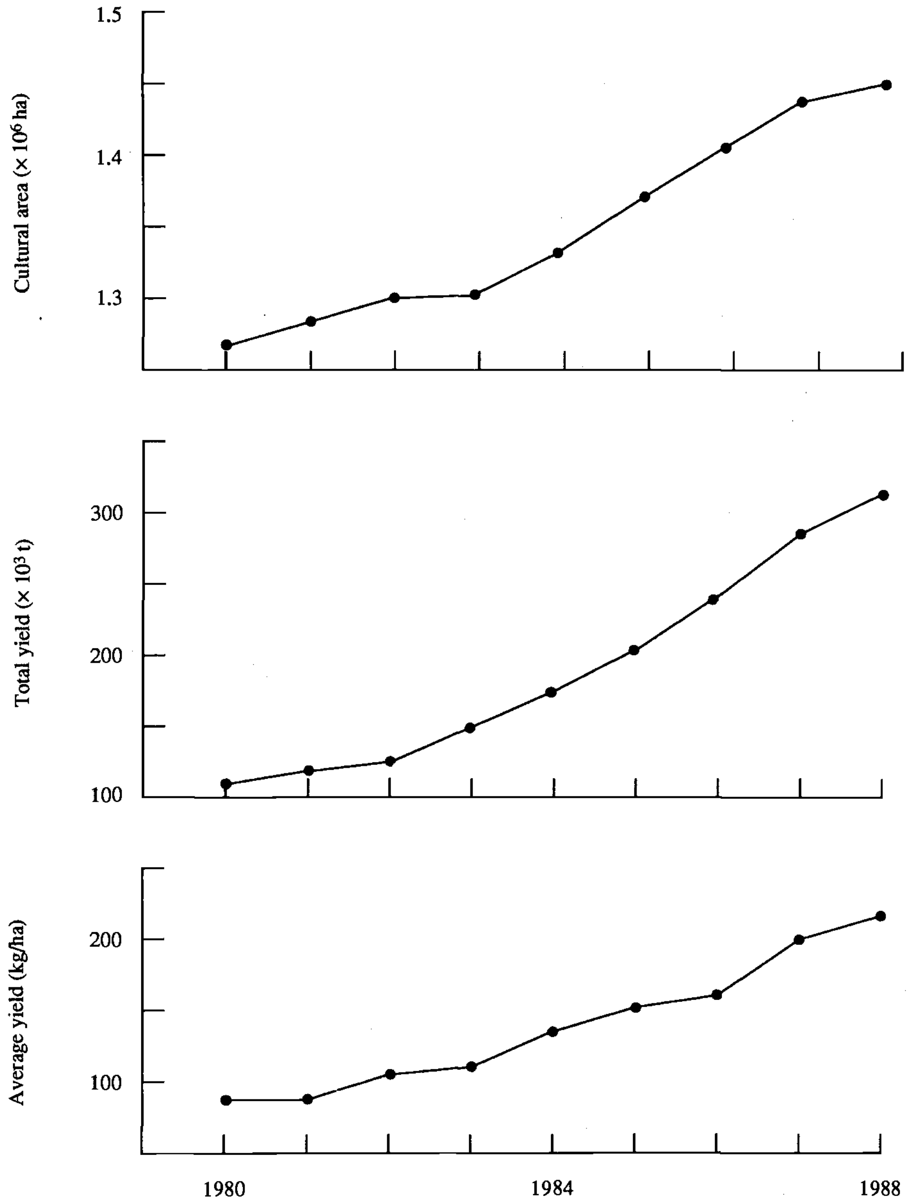

Fig. 1. Area under cultivation and yield of Chinese reservoirs.

for large and medium oligotrophic reservoirs. In general, the natural fish species are abundant and give a considerable yield (Table 1).

There is a positive correlation ($r = 0.77$) between water inflow and yield of wild species (Fig. 2). Higher inflow rates increase the spawning and feeding areas, and concentrate fish schools, making harvesting easier.

Stock enhancement is the main approach used to increase fish yields in open

Table 1. Fish species and yields of some reservoirs with open fisheries.

Reservoir	Area (ha)	No. of species	Yield (kg/ha)	Major species	Species in catch (% of yield)	Year
Danjiangkou	62 000	76	66–84	*Erythroculter* spp (20 piscivores)	50	1987–1988
Taipinhu	12 000	43	100	*Erythroculter* spp	56	1983
				Xenocypris spp, *Parabramis* spp, *Siniperca* spp, Crucian carp	38	
Tuanjie	2 130	20[a]	188	Crucian carp	40[a]	1980

[a] Records are not available, numbers are estimated.

fisheries. The introduction of new species into reservoirs is a common method of stock enhancement. It is low cost and efficient. The major species that have been introduced successfully on a large scale include the following.

- *Xenocypris*, including *X. davidi* and *X. microlepis*: In the Changdie area of Hunan Province, from 1982 to 1987, *X. davidi* and *X. microlepis* were introduced into reservoirs with a total area 4 780 ha. The catch of these fish increased to 106 800 kg by 1987, which represents a return of 500 000 CNY (4 CNY = 1 USD) (Zhou et al. 1988).

- *Hypomesus olidus*: This small cold-water fish has an optimum feeding temperature of 10–22°C. With a distribution limited to northeast China, its population size is usually small, and it has been insignificant in fisheries. Since 1984, however, this species has been introduced into several reservoirs in northern China. Its catchable population usually develops 2–3 years after introduction. For example, 2 years after introduction in Hunjiang reservoir (9 870 ha), 43 000 kg of fish and 1.16 billion eggs were harvested with a

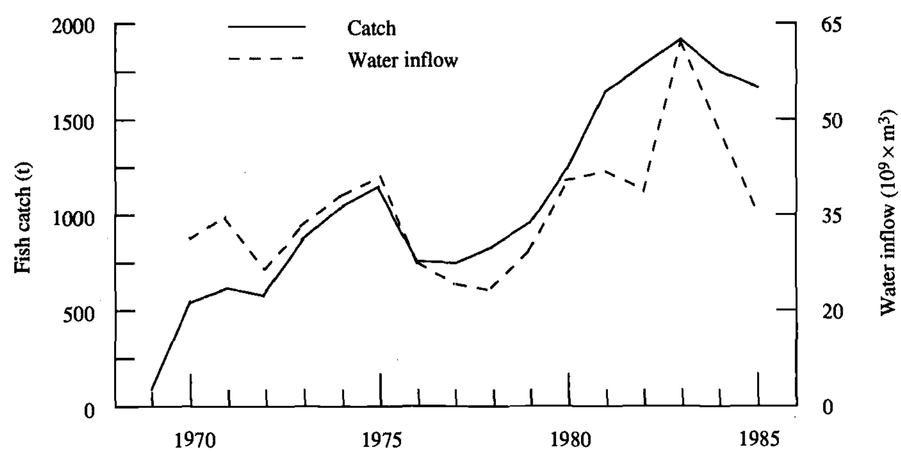

Fig. 2. Relationship between catch and water inflow in Danjiangkou reservoir (Xiong 1988).

value of 318 000 CNY. The cost of introduction was only 30 500 CNY (Shi and Wang 1988).

- *Hemisalanx* and *Protosalanx*: These fish have been introduced into some lakes and reservoirs in southern and northern China and have produced remarkable catches. In Tianchi Lake (298 km^2), the accumulated yield of *Hemisalanx taihuensis* in 1980–1986 reached 10 000 t. The value of *Hypomesus olidus* and *Memisalanx* spp has been enhanced considerably by demand from Japan in recent years.

Extensive Stocking

In extensive stocking, the primary approach is to stock fingerlings; enhancement of natural fish is secondary. There is no loading of manure or any feeding. Fish production depends upon phytoplankton productivity. This approach is suitable for most reservoirs.

The natural fish productivity of Chinese lakes and reservoirs ranges from 22.5 to 750 kg/ha (He 1987). Plankton-feeding silver carp and bighead carp are stocked as the major species, and they are the dominant contributors to total output (Table 2). In general, stocking 1 kg of fingerlings produces 5–10 kg of marketable size fish after 1–3 years (Li 1987), and the corresponding ratio of inputs to outputs is 1:1.3 to 1:1.7 (Wang et al. 1989).

The theory and practice of stocking and the techniques to harvest and to prevent escape have been quite well developed. Details on stocking are provided by Li (1988) and Li and Xu (1988); details on fishing techniques are given by Xu (1988) and Li and Xu (1988); and the prevention of escape is discussed by Xu (this volume).

Semi-Intensive and Intensive Culture

Pond fish-culture techniques are used in semi-intensive and intensive culture, which incorporates high-density stocking and fertilization or feeding. In the semi-intensive culture system, low quantity and quality feeds and fertilizers are given to fish to supplement their natural food intake. In the intensive culture system, high quality feeds and fertilizers are major inputs.

Fertilization is used to raise filter-feeding fish, usually with a conversion ratio 1.6–2.5 kg inorganic fertilizer per 1 kg of fish produced (Table 3). The main fertilizers used in Chinese reservoirs are calcium superphosphate, urea, liquid

Table 2. Fish yield and proportion of stocked species in extensively stocked reservoirs.

Reservoir	Province	Size (ha)	Yield (kg/ha)	% of Sc and Bh[a]	Year	Reference
Xinanjiang	Zeijiang	40 000	90	85	1983–1986	Li 1990
Fuziling	Anhui	1 200	227	97	1986	Gu 1988
Qingshan	Zeijiang	567	675	98	1969–1983	Li 1987

[a] Sc, silver carp; Bh, bighead carp.

Table 3. Effects of fertilization on fish yield.

Reservoir	Area (ha)	Yield (kg/ha)	Conversion ratio[a]	Cost (CNY/kg fish)	Reference
Duanjiashan	23	723	1.94	0.37	Tong and Gou 1988
Sanchaigou	16	711	2.09	0.40	Tong and Gou 1988
Chulou	53	402	2.20	0.96	Chulou reservoir office 1987
Chanbenling	14	729	2.48	0.77	Wu and Zhong 1989
Washan	73	458	1.61	na	Hao and Liu 1989

[a] Ratio of inorganic fertilizer to fish.

Table 4. Food consumption, manuring rates, and fish yields from Meichuan reservoir.

Year	Fertilizer (kg/year)					Yield (kg/ha per year)
	IF[a]	NS[a]	OC[a]	Grass	Wine waste	
1986	1 000	76 000	4 356	8 600	—	586
1987	2 800	147 000	10 344	—	50 000	639
1988	1 450	62 900	19 693	34 000	—	751
Annual average (kg/ha per year)	10.5	68.7	572.6	84	100.5	659

Source: Pan and Cheng (1989).
[a] IF = inorganic fertilizer; NS = night soil; OS = oil-seed cake.

ammonia, and ammonium hydroxide. With fertilization, fish production can be raised to 500–1 000 kg/ha, which is two to three times the natural level.

In some reservoirs, feeding is used, but this requires more capital to develop. The food conversion ratio for formulated feed is about 1.9–2.5. The yield from this technique is much higher than from fertilization, but shortage of feed is a limiting factor.

Fertilization and feeding can be combined and production is increased significantly. For example, Meichun reservoir (167 ha) was extensively utilized but overstocked (6 000 fish/ha per year), and the fish at times were stunted and did not reach marketable size (>500 g) within the expected period. Since 1986, the stocking density has been reduced to 3 000 fish/ha and the stocking ratio regulated to 45–55% silver carp, 35–45% bighead, and 10% common carp and grass carp. Feeding and fertilization have also been adopted (Table 4). As a result, yield has increased from 300 kg/ha to 750 kg/ha; return (the ratio of the number of recaptured fish of marketable size to the number stocked) has increased from 14.5% to 25%; and the harvested age has been reduced from 3–4 years to 2–3 years (Pan and Cheng 1989).

Combination of Extensive and Intensive Culture

Combined extensive and intensive culture attempts to use the reservoir ecosystem completely. Extensive stocking is carried out in open water; barriers are placed across coves with nets or dams; cages are set in coves or open water and grazing fish are fed in the cages; and wasted food and excreta from the fish in the cages are used to raise filter-feeding fish in coves and open waters. It is estimated that the wasted feed and excreta from fish in cages can enhance the yield of filter-feeding fish to 20–30% of cage production.

Cage culture in reservoirs developed quickly during the last decade. The most popular cage species are: common carp, tilapia, grass carp, blunt-snout bream, silver carp, bighead carp, and eels. The highest yields recorded from cage culture are: 115 kg/m^2 (common carp, Chuntangkou reservoir, 53 ha; Chang et al. 1988); 97.5 kg/m^2 (common carp, Haizi reservoir, 530 ha; Cui 1989); and 83.2 kg/m^2 (tilapia, Jindon reservoir, 200 ha; Xui et al. 1989). Reservoirs are suited for cage culture because they have deep running water (Table 5). Yields of over 75 kg/m^2 are produced in reservoirs that have water depths of 3–20 m, transparency of more than 1 m (Secchi disk), and dissolved oxygen over 5 mg/L at the cage sites.

The cost ratio of inputs (fingerlings usually account for 20–35% and food for 40–45%) to outputs for fed cages was about 1:1.4; for nonfed cages (silver carp and bighead carp), it was about 1:1.2; and for nonfed coves, about 1:2.0.

A survey of common-carp cage culture in Xichun Province by Zhang (1989) found that the relationship between the yield (kg/m^2) and stocking density (kg/m^2) was

[1] $Y = -69.442 + 18.5727\,X - 0.47666\,X^2$ ($r = 0.923$).

The relationship between net income (CNY/m^2) and stocking density was

[2] $Y = -391.330 + 73.5068\,X - 2.09783\,X^2$ ($r = 0.931$).

Zhang also pointed out that, at current technical and economic levels, the density that gives the highest yield is 19.5 kg/m^2, whereas the density that gives the highest income is 17.8 kg/m^2 (Fig. 3). Therefore, the optimum stocking rate is 18–20 kg/m^2. The shortage of feed is the main constraint in intensive cage-farming operations.

Integrated Farming Systems

Integrated farming systems for small reservoirs, which follow the integrated pond system, show great potential. Small reservoirs are widely distributed throughout the country, and account for 96.9% of the reservoirs and 26% of the total reservoir area in China. They play an important role in agriculture production and are used for fish farming. They can, therefore, accelerate the reform of agricultural production, particularly in hilly areas.

Compared with large and medium reservoirs, the water environment and the ecological conditions for fish species can be highly controlled in small reservoirs because of their size and proximity to the villages. The application of advanced technologies for intensive pond culture; the integration of fisheries with pearl culture, livestock and poultry farming, forage grass production, and horticulture; and good water and soil conservation techniques can turn these reservoirs into comprehensively managed enterprises. Integrated fish farming is a useful model for complete development of resources and fish culture in small reservoirs.

Since 1986 in Zhejiang Province, this production technique has been extended

Table 5. Some results of cage culture practices in Chinese reservoirs.

Reservoir	Area (ha)	Cage area (m^2)	Cage size ($m \times 39\ m \times m$)	Average yield (kg/m^2)	FCR[a]	Reference
Silver carp and bighead carp						
Xujiaya	900	23 688	$7 \times 4 \times 2$	8.2	—[b]	Lou et al. 1989
Grass carp						
Xianghongdin	4 000	728	—	8.9	—	Yang and Xu 1986
Common carp						
Chutangkou	53	1 138	—	115[c]	2.12	Zhang 1989
	—	900	—	50[d]	2.24	Zhang 1989
Haizi	—	3 300	—	97.5	—	Cui 1989
Songhuahu	33 330	184	$4.3 \times 4.3 \times 2.5$	56.3	—	Liu 1988
Kalun	330	270	$4.3 \times 4.3 \times 2.5$	37.8	—	Liu 1988
Xingxingshao	1 000	400	$5 \times 5 \times 2.5$	75.9	—	Liu 1988
Jindou	—	50	—	177	1.90	Xui et al. 1989
Tilapia						
Shitoushan[e]	17	420	$7 \times 4 \times 2$	17.5	2.50	Yang et al. 1987
Jindou[f]	200	670	$2 \times 2 \times 2$	83.2	1.90	Xui et al. 1989
Dahoufan[g]	5 300	325	$5 \times 5 \times 2.5$	72.5	—	Liu 1988

[a] FCR = Food conversion ratio.
[b] Nonfeeding.
[c] Adults.
[d] Fingerlings.
[e] 32° N Jiangso Province.
[f] 35° N Shandong Province.
[g] 41° N Leioling Province.

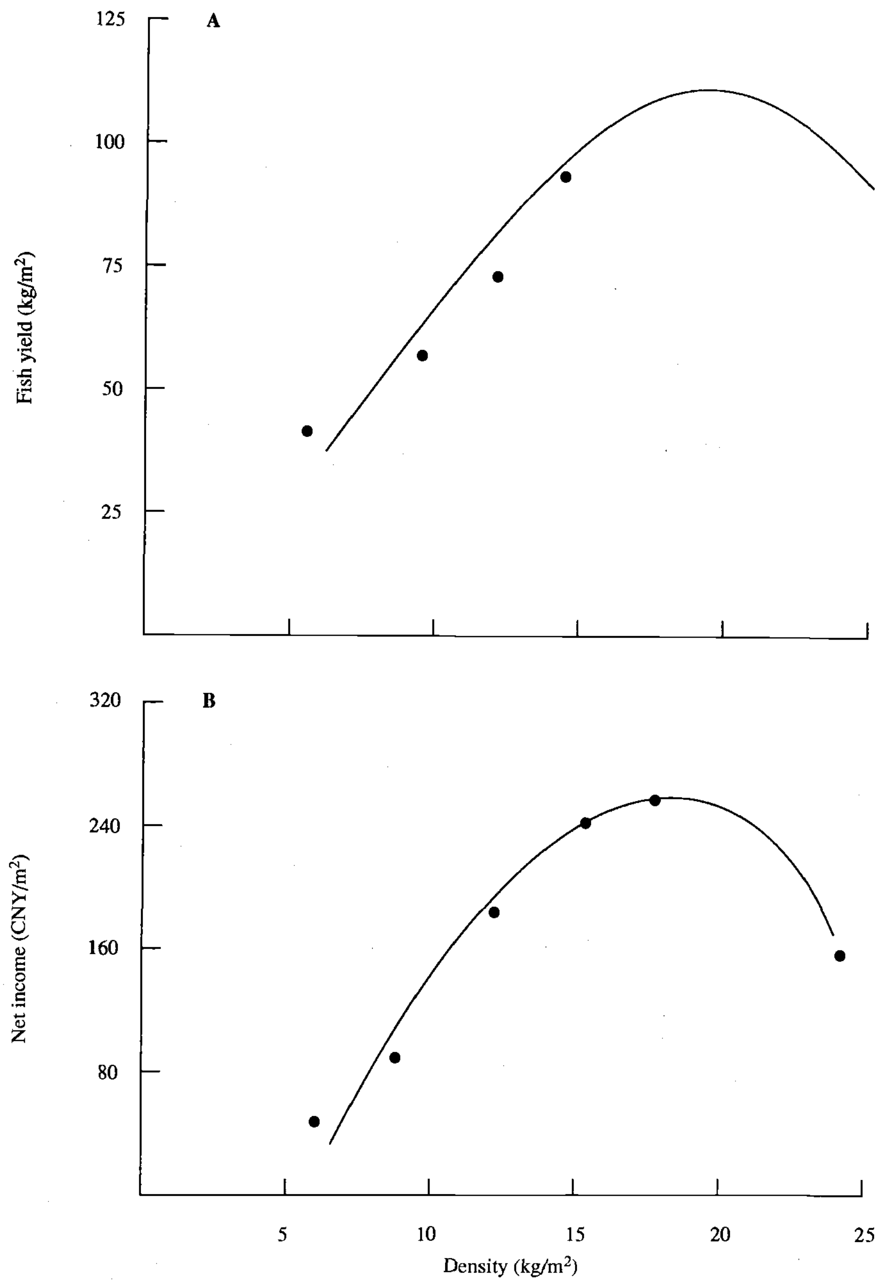

Fig. 3. Relationship between fish yield and stocking density (A) and between net income and stocking density (B) in cage culture of common carp in seven reservoirs in Sichuan Province.

to a total area of 1 715 ha of small reservoirs. The average fish yield in 1985, 1986, and 1987 was 255.3, 414.5, and 756.6 kg/ha, respectively, and gross income was 434, 1 177, and 2 497 CNY/ha respectively (Cheng and Wu 1989).

Conclusion

The geography, economy, and consumption habits in China are diverse, and no uniform fishery practice can be adopted throughout the country. Therefore, the technology must be modified to suit local conditions. Any development strategy must be based on scientific study combined with economic and social analysis of the specific situation.

Because of the large scale of the investigations, and the special problems posed by water bodies of different types and geographic locations, there is a great need for a general theory on the productivity and biological cycling of matter in water bodies. In other words, a theory is needed for water ecosystems. Although such a theory must be the scientific basis for solving particular problems, at present, it is only in the initial stage of its development.

When reservoirs are managed as open-water ecosystems, the exploitation strategy to be developed must consider the balance between the carrying capacity of the reservoir and its utilization pressure.

Yields from reservoirs are highly variable and depend on geographic location, natural productivity, and fisheries management (De Silva 1988). It is estimated that only 20% of the natural food resources in Chinese reservoirs have been utilized, and that natural food resources can produce 22.5–750 kg of fish per hectare. Full utilization of the natural food resources in the 2 million ha of reservoirs in China would mean that production of 1.5 times the 1988 level could be attained. On the other hand, because the production of semi-intensive and intensive culture can exceed 1 000 kg/ha, the potential fish production from highly managed reservoirs could be much higher.

Cage culture is becoming increasingly important in Chinese reservoirs. It was estimated in 1988 that there was more than 400 ha of cage culture in inland waters. The shortage of resources to produce compounded fish feed remains a constraint to further adoption of this technology.

It is necessary to caution that improper fertilization and heavy feeding in reservoirs for several years may result in eutrophication, which can affect culture and other activities. Studies on nitrogen and phosphorus input–output in intensive cages in Dingshanhu Lake have shown that the ratio of loss to input (seed and feed) for N is 68.14% and for P is 82.46% (Shi and Liu 1989). To produce 1 t of carp, the P lost to the environment is 55.7% (for a food conversion ratio (FCR) = 2.0), e.g., 90.13% of P is lost during feeding (Beveridge 1987). A combination of intensive cage culture with extensive stocking of planktivorous fish in open waters might be a good way to use the lost nutrients from cages and prevent eutrophication.

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Reservoir Fishery Practices in Mountain Areas in China

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Jiande county, in the western mountainous area of Zhejiang Province, contains 6 560 reservoirs and ponds that have an area of 4 600 ha suitable for fish production. The largest reservoir is Fuchun Jiang. Fuchun Jiang reservoir is stocked annually with about 0.8–1.5 million carp fingerlings (15 cm), supplemented by juvenile crabs. Closed fishing areas and seasons are imposed, mesh size is regulated, and the use of explosives and poisons is prohibited. Cage culture of rainbow trout, grass carp, and blunt-snout bream is also practiced. In small reservoirs, ponds, and dammed reservoir coves, intensive culture is practiced, often integrated with poultry and livestock. Water bodies are manured either with fermented manure or artificial fertilizer. The average yield from coves is 1 322 kg/ha per year; from ponds and small reservoirs, it is 1 312 kg/ha per year. The capture rate in these small water bodies is above 80%.

Jiande county is in the western mountainous area of Zhejiang Province (2 321 km^2). The soil is acidic and the climate is subtropical with an average annual temperature of 16.9°C, 160 days of rain, and an annual average of 1 500 mm of precipitation. It has a frost-free period of 254 days. There are 1 941 h of sunshine per year; the sunshine rate is 44%; and the total incident radiation is 446.9 J/cm^2. The county is rich in water resources. There are four large rivers (Xinan Jiang, Shouchang Jiang, Lan Jiang, and Fuchun Jiang) with a catchment area of 2 331.6 km^2. The total water area in Jiande County is 7 667 ha, of which 4 667 ha are suitable for fish production.

Fish production in Jiande County has markedly increased since the late 1970s. The total yield from 1983 to 1989 was 14 090.52 t, or 49.6% of the total yield since liberation (1949–1989). In 1989, the total output of aquatic products reached 3 084 t, about four times the yield in 1978. The yields of some rare aquatic products such as rainbow trout, mitten crabs (*Eriocheir sinensis*), and freshwater pearls were 40 t, 75 t, and 576.5 kg, respectively.

The county is divided into three fishery zones (Table 1) for the planning and development of fisheries. The different technical measures adopted in each zone are discussed in this paper.

Table 1. The fishery zones of Jiande County.

Fishery zone	Total water area (ha)		Main characteristics
	Suitable for fish production[a]	Fuchun Jiang reservoir	
Culturing and restocking area of Fuchun Jiang reservoir	21 734	830	Centralized waters, sufficient sunshine, suitable water temperature, plenty of feed and water resources
Cold-water area below dam of Xinan Jiang hydroelectric power station	1 123	989	Cold waters below dam, 8–20.4°C, transparency is above 8 mg/L, plenty of aquatic plants
Cultural area of ponds and small reservoirs	810	—	Abundant and scattered, plenty of grass, major function irrigation, water acidic

[a] The fishery water area of the reservoir is measured as 70% of the total water area at the normal water level.

Table 2. The hydrological features of Fuchun Jiang reservoir.

Features	Main water body		Dammed cove
	Warm-water zone	Cold-water zone	
Water area (ha)	1 830	989	334
Mean depth (m)	10	6	3.5
Maximum depth (m)	27	14	9
Water level drop (m)	1–2	1–2	0.3[a]
Velocity of flow in nonflood period (m/s)	0.6	1.5	–
Velocity of flow in flood period (m/s)	2.2	2.5	–
Annual water exchange (times)	71.6	71.6	3–5[a]

[a] Just some coves.

Fishery of the Fuchun Jiang Reservoir

Located in two counties and one city (Jiande, Tonglu, and Lanxi), Fuchun Jiang reservoir was impounded in December 1968. It is a river-type reservoir in the middle section of the Qiantang Jiang River that is used for flood protection, hydroelectric power, and irrigation. The normal reservoir capacity is 440 million m^3; the total water area is 5 600 ha, of which the available fishery area in Jiande county is 3 153 ha (the main water body is 2 819 ha and the dammed cove 334 ha) (Table 2). The water temperature of the main reservoir is above 15°C for 8 months and ranges from 5°C to 32°C; near the dam, the temperature range is 8–20.4°C. Transparency is above 110 cm; pH 7.1; dissolved oxygen 7.51 mg/L; chemical oxygen demand (COD) 2.26 mg/L; total P (PO_4^{-3}-P) 0.047 mg/L; total Fe 0.055 mg/L; Ca^{+2}

Table 3. Status of the food resources in Fuchun Jiang reservoir.

Item	Genera and species	Biomass	Dominant groups	Biomass
Phytoplankton	59	0.5790 mg/L	Bacillariophyceae Chlorophyceae	0.2258 mg/L 0.2200 mg/L
Zooplankton	110	0.5448 mg/L	*Rotaria* sp. *Cladocera* sp.	0.1416 mg/L 0.2833 mg/L
Benthos	58	159.7–373.6 g/m^2	*Corbicula fluminea* *Nephthys* sp. *Bellagama* sp. *Unio douglasiae*	
Aquatic plants	—	51.9–575.2 g/m^2	*Vallisneria spiralis*	1.5×10^5 t[a]

[a] Wet weight.

Table 4. Changes in fish resources in Fuchun Jiang reservoir.

Before construction of dam	After impoundment
Dominant	
Xenocyprinainae *Cyprinus carpio* *Megalobrama* sp. *Hypophthamichthys molitrix* *Aristichthys nobilis*	*Hypophthalmichthys molitrix* *Aristichthys nobilis* *Cyprinus carpio* Xenocyprininae *Megalobrama* sp.
Characteristics of resource changes	
There are many migratory species, such as *Macrura reevesii*, *Coilia ectenes*, true mullet (*Mugil cephalus*), true eel (*Anguilla japonica*), soles (Cynoglossidae), etc., and also plenty of mitten crabs. The resources increased by reproducing naturally.	The migratory fishes, except true eel, have all disappeared. Initially, the mitten crab disappeared. Since 1973, the crab resources have greatly increased due to continual artificial release. The production of bighead and silver carp is 60% of the catch. Artificial release is a main measure to increase resources.

12.79 mg/L; and alkalinity 2.4 German degrees. The reservoir is rich in food resources (Table 3), and a number of significant changes in the fish fauna have occurred since impoundment (Table 4).

The present fishery practices in Fuchun Jiang reservoir are schematically represented in Fig. 1. These practices have enabled maximum utilization of the water resource.

Stock Protection

Measures have been taken to facilitate the breeding of carp, crucian carp (*Carassius auratus*), blunt-snout bream, and silver chub. These measures include setting up artificial nests, imposing closed fishing zones and fishing seasons,

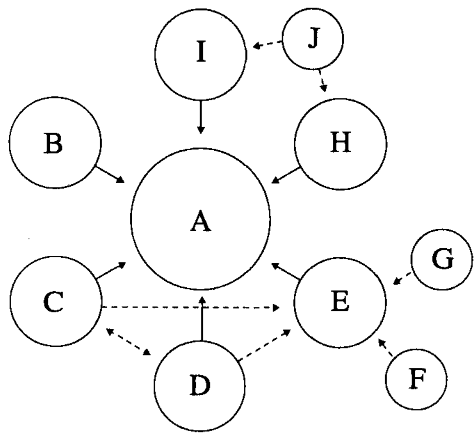

Fig. 1. Schematic of components and management of fisheries in Fuchun Jiang reservoir: A. Fuchun Jiang reservoir; B. restocking (artificial and natural); C. cage culture; D. pearl culture; E. dammed reservoir cove; F. raising fish combined with livestock and poultry; G. raising adults or fingerlings; H. fishing; I. protection (breeding groups, breeding grounds, young fish, and crabs); J. management of fishery administration.

limiting fishing boats and the number of people fishing, limiting mesh size and catchable size, controlling fishing intensity, and banning explosives, poison, electric fishing, and other destructive fishing methods.

Stocking

Fish fingerlings and crab megalopa that are released into the reservoir annually (Table 5) influence the composition of the fish fauna in the reservoir.

Fish Capture

The main fishing gears are trawls and gill nets. The bulk of the catches consist of silver carp, bighead carp, silver chub, common carp, *Erythroculter*, and crabs. Silver carp and bighead carp account for 50–60% of the total yield, and their capture rates are 33.05% and 17.14%. The crabs are caught with single gill nets and crab traps and their capture rate is 4%. In 1989, the fish yield of the reservoir reached 231 kg/ha, including crabs and shrimps.

Table 5. Fingerlings stocked in Fuchun Jiang reservoir (1988).

Species	Size (cm)	Number ($\times 10^4$ fish)	Percentage
Grass carp	13–17	5.61	5
Silver carp	15	34.81	31
Bighead carp	15	62.87	56
Blunt-snout bream	10–13	8.98	8
Total		112.27	100

Dammed Reservoir Coves

The damming of reservoir coves started in 1970; now there are 78 coves that provide a total available fishery area of 334 ha. These reservoir coves provide good culture conditions (broad water area 2–5 m deep, sufficient sunshine, good vegetation on the surrounding embankment, and abundant feed resources). Because the soil is acidic, lime is added periodically to adjust the pH (the dosage of quick lime is 225–300 kg/ha, 1–2 times/month). The traditional cultivation techniques are combined effectively with intensive cage culture, which amounts to 0.5–1.5% of the reservoir cove area. Herbivorous and filter-feeding fish are cultured in the cages.

The average yield from the dammed reservoir coves in 1989 was 1 322 kg/ha; the highest yield was 3 779 kg/ha (Table 6).

Cage Culture

The cage culture of grass carp and blunt-snout bream (*Megalobrama amblycephala*) began in various reservoirs in 1980 to exploit the weed resources in the water and on the land around the reservoir. There are 4.25 ha of cages that yield an average of 4.2 kg/m^3; the highest yield was 42 kg/m^3 (Table 7).

Table 6. Information on culture[a] in the dammed coves for Fuchun Jiang reservoir.

	Stocking		
Species	Size (g)	Density (fish/ha)	Capture size (kg)
Silver carp	50	1 500	>0.6
	>150	500	
Bighead carp	50	450	>0.6
	>150	200	
Grass carp	75	225	>0.6
Blunt-snout bream	40	450	>0.25
Common carp	50	300	>0.5
Carassius auratus	40	650	>0.15
Black carp	200–250	30	>0.1

[a] Total production from the reservoir was >1 300 kg/ha.

Table 7. Details on cage culture practices of herbivorous fish in Fuchun Jiang reservoir.

	Stocking		
Species	Size (g)	Density (fish/ha)	Harvest size (kg)
Grass carp	50[a]	4	>0.75
	>150[b]		
Blunt-snout bream	40–50	6	>0.25

Note: Survival rate of grass carp was 70% and blunt-snout bream was 95%. Total production was 4 kg/m^3.

[a] Cage size 13.3 m × 10 m × 3 m.

[b] 5–10 bighead carp, 5 silver carp, 1 500 common carp, and 20 *Carassuis* sp. were also raised in each cage.

Table 8. Results of rainbow trout cage-culture below the dam at the Xinan Jiang power station.

Cage grade[a]	Stocking Size (g)	Stocking Density (fish/m^3)	Harvesting Size (g)	Harvesting Production (kg/m^3)
First	0.3	1 560	35	30
Second	35	200	125	17
Third	125	50	>500	>15

[a] Cages are closed. First cages are 2 m × 2 m × 1 m; second and third cages are 4 m × 4 m × 2 m.

Rainbow trout were introduced in 1980, and cultured in cages in the cold-water zone below the dam of the Xinan Jiang reservoir. A rainbow trout farm has been established, where rainbow trout are raised from young fish (0.3 g) to commercial-size fish using a series of three cages. The farm has 0.33 ha of cages and a culture system for rainbow trout that includes artificial propagation, rearing of fingerlings, adult fish culture, and the production of pellet feed (Table 8).

Freshwater Mussel Culture for Pearls

The main waters of the reservoir, dammed reservoir coves, and ponds all are polycultured with freshwater pearl mussels. The annual pearl yields are shown in Fig. 2.

Fishery of the Small Reservoirs and Ponds

There are 121 small reservoirs and 6 359 ponds that provide a total water area of 1 447 ha for fisheries. These reservoirs and ponds are characterized by low water depth, variable extent of water storage, easy loss of nutrients and plankton, pH 5.5–6.5, and limited natural fish resources. Intensive culture started in 1983, and yields increased to 1 312.3 kg/ha in 1989. The culture methods are similar to those used in dammed reservoir coves (Tables 9 and 10). Cage culture is also practiced in the small reservoirs.

Fingerlings of common carp and crucian carp, or of other species, are regularly stocked to improve these reservoirs and ponds. Harvesting is done with trawl nets and gill nets, as well as electric fishing methods. Capture rates are above 80%. In small ponds, the fish are harvested by draining the pond.

Comprehensive Exploitation

As a subsystem of the agricultural ecological system, the production and economy of a reservoir is closely connected with other ecosystems. The whole reservoir is scientifically used to maximize resource utilization. The reservoir is used for flood protection, water storage, shipping, aquaculture, and tourism (sport fishing is planned). The reservoir coves are used for fish culture, pearl culture, livestock and poultry, and economically aquatic plants such as lotus and wild rice.

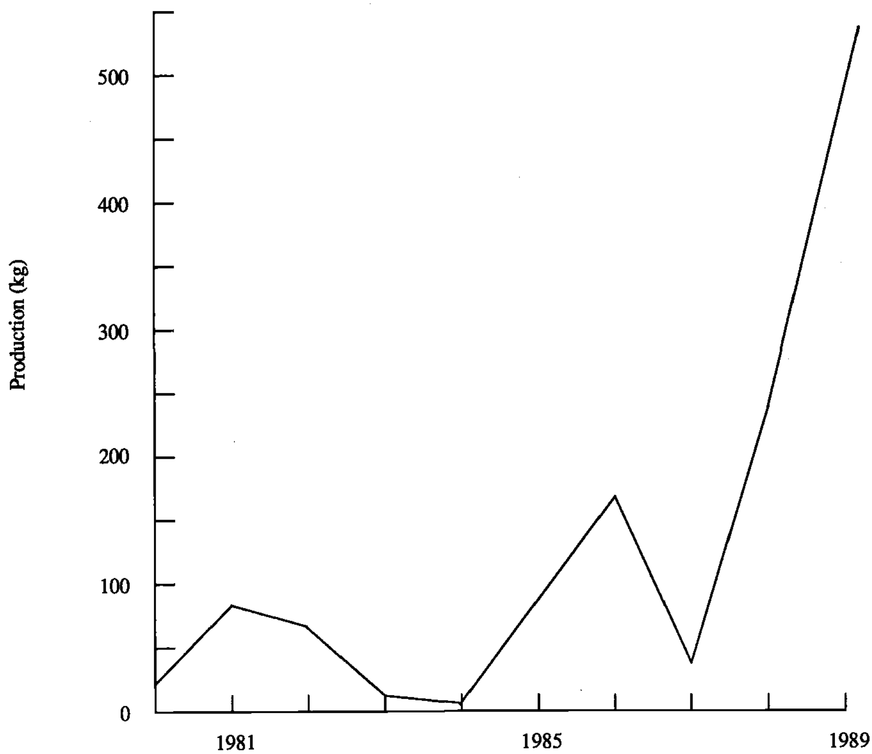

Fig. 2. Annual pearl production in Fuchun Jiang reservoir.

Table 9. Stocking and harvesting details of pond culture.

Species	Stocking Size (g)	Stocking Density (fish/ha)	Harvest size (kg)
Silver carp	40	1 300	>0.6
	>150	500	
Bighead carp	40	650	>0.6
	>150	200	
Grass carp	30–50	720	>0.7
	200	180	
Blunt-snout bream	40	600	0.25
Carassius auratus	25	375	0.15
Common carp	15–25	150	0.40
Total		4 675	

Note: Production was more than 1 500 kg/ha.

The buffer zone of around the reservoir is planted with crops, vegetables, and grasses. The hillsides around the reservoir can be used for fruit trees, tea, mulberry, medicinal herbs, and other suitable trees for conservation of water and soil. The water below the dam can be used for irrigation, water power, and the culture of rainbow trout. Through multiple usage, a fine ecological balance has been gradually achieved.

Table 10. Stocking and harvesting details of small reservoirs (production more than 950 kg/ha).

Species	Stocking Size (g)	Stocking Density (fish/ha)	Harvest size (kg)
Silver carp	50	1 100	>0.6
	>200	400	
Bighead carp	50	650	>0.6
	>200	250	
Grass carp	50	400	>0.6
Blunt-snout bream	30–50	450	0.25
Carassius auratus	30–50	400	0.15
Common carp	30–50	250	0.50
Total		3 900	

Fry Production and Economic Fish Culture

Much attention has been paid to the construction of fry-rearing facilities in the county. The annual fry production is over 30 million, and over-wintering fingerling production is about 10 million (of which about 30% are 13–15 cm and 60% are >15 cm). Fingerlings are produced in ponds, cages, and reservoir coves using mono- and polyculture.

Feed Supply and Fish Culture

Pellet feeds have been developed in the county using wheat bran, rice bran, wheat flour, rapeseed cake, distillers' grain, and fish meal. The annual output of pelleted food is 980 t. (Small plants for pelleting food are spread out to meet the needs of the industry in mountainous areas). Other feed resources for fish culture are: upland grasses, dredged up water weeds; grasses (*Lolium perene*, *Sorghum sudanensis*, *Millium effusum*, and *Ixeris denticulata*); and cultivating aquatic plants (*Wolffia arrihiza*, *Lemna* sp., *Azolla caroliniana*, and *Azolla imbricata*).

Manure is an indirect food for fishes. Excrement of some livestock and poultry can be directly used as fish food. Great importance is attached to manure supply, and manure-supply bases have been established. The problem of getting sufficient manure is solved by cultivating fish with poultry and livestock, buying manure from poultry and livestock farms, using green manure, and buying small amounts of chemical fertilizer.

Discussion

The development of cage culture in reservoirs along with extensive culture is a good way to increase fish production rapidly. However, the effectiveness of culture will decrease if it exceeds the rearing capacity of the reservoir. The production of herbivorous fish in cages should be adjusted to suit the grass resources of the reservoir. Only by reasonable planning of weed resources, can cage culture be made economic. Through years of practice, it is thought that the total cage culture area should cover 1–2% of the water area.

The mitten crab is an expensive aquatic product. Mitten crab larvae (80–150 kg) have been released each year for the past few years in Jiande County. Commercial mitten crabs over 125 g can be caught after 1 year. In future, 250–300 kg/year of mitten crab larvae will be released. To increase crab-capture rates, the release of young mitten crabs instead of mitten crab larvae, will be adopted if possible.

The cold-water area of the upstream reservoir in Xinan Jiang is not suited for silver carp and bighead carp. Small coarse fishes have been dominant in these waters. On the basis of the success of rainbow trout cage culture, artificial release of rainbow trout in Fuchun Jiang needs further study. Because rainbow trout are carnivorous, great care will need to be taken before they are released into inland waters to determine whether they will hurt the economic fish species.

Technological and Socioeconomic Assessment of the Magat Reservoir Fishery, Philippines

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The technological and socioeconomic conditions of Magat reservoir fisheries were assessed to develop improved fishing gear and technology suitable for the conditions of Magat reservoir. More than 59% of the people who fish own their fishing gear and about 40% own boats. The fishing gear used includes: gill nets, hook and line, fish and shrimp traps, fish cages, and cast nets. On average, people fish for 5.64 h/day for a maximum of 270 days/year. The average annual fish catch of 2.58 t is dependent on the type of gear and boat used, and upon the fishing effort exerted in terms of the number of hours per day. The average annual per capita income for a Magat fishing household is about 2 885 PHP (1 USD = 20 PHP) and is dependent on the educational level of the person fishing. On average, those who fish have received 7 years of formal education. Gross income, as high as 5 426 PHP/month, shows that fishing within the Magat reservoir area is lucrative.

Magat reservoir, located in northern Luzon, is the second largest reservoir in the Philippines. It has an area of 4 460 ha, a maximum depth of 80.5 m, and is located at an elevation of 1 500 m. It was formed when the Magat high dam complex was constructed in the foothills of the Cordillera Mountain Range. The reservoir extends upstream about 50 km from the dam to a point just downstream from the town of Bagabag.

The phenomenal growth of the reservoir as a major source of freshwater fish in the Cagayan Valley region started in October 1982, when the Bureau of Fisheries and Aquatic Resources stocked it with *Oreochromis niloticus* and 10 000 bangus (*Chanos chanos*) fingerlings. By 1986, an estimated 3.15 million fingerlings had been stocked in the cages within the reservoir (MRMP 1986).

The fishery in Magat reservoir is the most productive in the country (Guerrero 1987). Total fish catch in the reservoir was 178.46 t in 1987 and 171.36 t in 1988. This excludes fish production from cages in the reservoir (Obungen J.P., National Irrigation Administration, Magat River Multi-Purpose Project, personal communication). Because fish production and supply make a significant contribution to the region, the Magat reservoir fisheries should be developed.

In this paper, the fishing gear used in Magat reservoir, and the fishing technology employed in the area are discussed.

Fishing Gear and Technology

The Magat reservoir, although a multispecies fisheries resource, allows the use of a limited number of fishing gear: gill nets (*sigay*); longlines (*kitang*); cast nets (*tabukol*); seines (*bobo*); pole and line (*liw-liw*); and spears.

Gill Nets

About 52.6% of those who fish in the reservoir use gill nets. Gill nets are made of monofilament *tansi* with a preferred mesh size number 4 (8 cm), although 16.7% of people do use mesh size number 3 (10 cm). Gill nets must have a minimum stretch size of not less than 6 cm (mesh size number 5). The number of units owned by one person ranges from 1 to 25. Nets are laced together, but do not exceed 500 m in total length.

Stationary gill nets, set just below the water surface, are used to catch the most common commercial fish — *Tilapia* spp; common carp (*Cyprinus carpio*); and, in some instances, the Magat catfish (*Arius magatensis*). The gear is set just before dusk, left overnight, and hauled in before sunrise. Setting and retrieving the net requires the use of a boat. The economic life span of the gill net is 3 months. Average daily volume of fish caught (mixed species) ranged from 1 to 5 kg.

Longlines

Simple and short longlines, locally known as *kitang*, are used in Magat reservoir on a limited scale. A more or less similar gear, the hook and line, locally known as *banniit* is used more commonly along the shallow parts of the reservoir. *Banniit* is a barbed hook, a line, and a pole. As many as 150 hooks and lines are used, but about 57.1% of those who fish operated about 25 baited barbed hooks and lines. Small shrimps, frog meat, earthworms, and trash fish are used as bait. The barbed hooks are fastened to a line about 1 m long that is connected to a bamboo stake driven firmly into the ground in shallow water. The hooks drift freely just under the water surface. Setting is usually done in the morning; the catch is retrieved in the afternoon.

Cast Nets

Cast-net fishery in the reservoir is not as extensive as in the shallow, more or less stagnant, portions of the Magat River. Very few people (4%) own and operate cast nets.

Cast-net operation in Magat reservoir is similar to that described by von Brandt (1972: 195–203). The cast nets are used in very deep water (60 m or more in Magat reservoir). The net is cast into the water and spreads itself as it sinks.

The cast nets used in Magat reservoir usually have a radius of 2–3 m and have a central line that is used to haul in the net.

Fish Traps

A wide variety of fish traps are used in Magat reservoir, mainly for groups of fish and crustaceans. Fish traps vary in size and shape, as well as in the materials used for construction.

Fish traps made of 20-mm-mesh wire screen are popularly used to trap *Tilapia* spp, *C. carpio*, *Theraphon plumbeus*, and *Arius magatensis*. The entrance is a slit leading into a heart-shaped chamber. This trap usually contains discarded incandescent bulbs, which are luminous underwater and attract fish.

A tubular trap is used to catch shrimps. It has an entrance that is tapered away from the opening of the gear, and is closed on the smaller end. The shrimp get inside but cannot retreat. Shrimp traps, known as *balingato*, are made of bamboo sticks and have an opening on the side. They range in length from 30 to 35 cm, and have front and rear end diameters of 15 and 10 cm, respectively.

Shrimp traps are set at about 1600 hours in shallow, protected portions of the reservoir. A bamboo stake is set firmly in the ground and the gear is connected by a line to the stake. Hauling is done the following morning. Ten units of this gear catch about 500 g of shrimp overnight.

Fish Cages

The cages used in Magat reservoir are made of bamboo and synthetic netting and range in size from 4 × 4 m to 12 × 14 m.

After they have been used to produce market-size tilapia at least three times, the cages are no longer stable enough to support the tilapia population and are used as a fishing gear. One side of the worn-out fish cage is lowered into the water, and fish are caught by lifting the net from the water when the fish gather over it.

Fishing with fish cages usually takes place during the onset of the full moon when the fish, usually freshwater grunt (*Therapon plumbeus*), are attracted to the surface and enter the lowered fish cages. Fish catch per day ranges from 0.25 to 25 kg. The catch is good during the peak season for freshwater grunt (October–February) and during moonlit nights.

Socioeconomic Status of Magat Reservoir Fisheries

Those who fish in Magat are encouraged to organize themselves into cooperatives and associations. People residing in the reservoir towns of Isabela, Nueva Vizcaya, and Ifugao provinces are given preference for fishing in the reservoir.

The average annual per capita income for Magat reservoir fishing households is about 2 885 PHP (Table 1)(20 Philippines pesos (PHP) = 1 United States dollar (USD)). The average person fishing is slightly over 31 years old, has received 7 years of formal education, and has an average household size of 4.82 family members, of whom 1.48 are dependents. Slightly more than 17% of the fishing households have alternative income sources from farming a small parcel of land or operating a few fish cages.

Table 1. Socioeconomic profile of those who fish along the Magat reservoir.

Fishing grounds	Sample size	Average annual gross income per capita (PHP)	Average age	Average years of formal education	Average household size	Average number of dependents	% of households having other income source
Baligatan	24	3 878.95	25.91	7.33	5.70	1.75	25.00
Dallao	27	4 983.33	38.33	6.67	4.33	1.67	11.11
Halag	18	2 101.08	33.17	6.17	4.28	1.50	16.66
Namnama I	21	2 176.21	29.42	6.00	4.14	1.00	0
Namnama II	12	1 286.61	28.75	9.50	5.67	1.50	0
Totals and means	102	2 885.43	31.12	7.13	4.82	1.48	17.59

About 56% of the people own their fishing gear; almost 40% of them own their fishing boats, of which only 17% are propelled by a 7.5-kW diesel engine (consuming about 1.6 L of fuel/day, Table 2). Most fishing boats (85%) are not motorized. The average person makes a fishing effort of about 5.64 h/day on a maximum of 270 days/year, and has an average annual catch of 2.58 t.

The average annual per capita income is dependent on the educational level of the person who fishes. Another important observation is the relationship between fishing effort, boat and gear ownership, and fish catch. As expected, the more hours per day spent fishing, the greater the volume of fish caught. The most effective fishing effort was 8 h/day. Volume of catch is also dependent upon the boat used. There are two types of boat: nonmotorized boats are used mainly for fishing; whereas, motorized boats are also used to transport large volumes of fish harvested from fish cages, and to transport inputs needed in fish cage operations (Quijalvo, N.P., Magat reservoir fish cage operator, personal communication).

Similarly, volume of fish catch is dependent on the type of fishing gear used. Of the gears, the gill net is the most widely used (53% of the respondents use this type of gear); 35% use fish and shrimp traps.

Cost and Return Analysis

Each person fishing in the Magat reservoir invested, on average, a total of 8 397 PHP for their boat (4.2%) second-hand 7.5-kW diesel engine (89.3%), and fishing gear (6.5%).

Annual operating expenses averaged 10 545 PHP, which included: costs of fuel and lubricants used while fishing and transporting fish to the fish landing port (5 665 PHP); food while fishing (3 390 PHP); and marketing costs (1 290 PHP), which include a fish landing fee equivalent to 0.50 PHP/kg of fish caught, and an annual fishing permit (200 PHP).

Revenue is from the sale of fish at an average selling price of 36.20 PHP/kg regardless of species (Table 3). From an average annual catch of 2.58 t, of which about 10% is for household use, each person realizes annual gross sales of 84 056.40 PHP.

Table 2. Fishing activity in Magat reservoir.

Fishing grounds	People owning gear (%)	People owning boat: Motor (%)	People owning boat: Nonmotor (%)	Effort per day (h)	Average annual catch per person (t)
Baligatan	75.00	4.17	37.50	5.54	2.70
Dallao	55.56	3.70	29.62	8.66	3.48
Halag	33.33	2.08	33.33	5.00	1.55
Namnama I	66.66	0	28.57	6.16	2.58
Namnama II	50.00	16.55	33.33	2.83	2.58
Means	56.11	6.65	32.47	5.64	2.58

Table 3. Average prevailing market price at Baligatan fish landing port (October 1989).

Fish species	Common name	Local name	Price (PHP/kg)
Tilapia (all species)	Tilapia	Tilapia	37.50
Cyprinus carpio	Common carp	Butsog, burasi	37.50
Therapon plumbeus	Freshwater grunt	Ayungin, tutut	14.10
Arius magatensis	Magat catfish	Kurilao	40.25
Ophicephalus striatus	Mudfish	Dalag	45.00
Clarias spp	Catfishes	Paltat, hito	45.00
Anguilla sp.	Eel	Igat	60.00
Glossogobius sp.	Goby	Bunog, biya	25.00
Carassius carassius	Crucian carp	Imelda fish	15.00
Marcrobrachium sp.	Freshwater shrimps	Lagdao, udang	43.00
Average selling price			36.20

For the purpose of this analysis, it is assumed that each person spent a total of 270 days/year fishing, so average annual gross income is projected at 65 114 PHP. The high gross income realized by those who fish demonstrates that fishing the Magat reservoir is a lucrative business.

Constraints

The constraints threatening the efficiency of fishing in Magat reservoir are, first, the limitations on the type of fishing gear and, second, the establishment of specific "territories" for certain groups of people in given fishing grounds within the reservoir. The seasonality and availability of certain fish species during a specific period also affect productivity.

Conclusions

The Magat reservoir plays a significant role in providing a livelihood and a high-protein food supply for an increasing number of rural families. Although fishing gear and technology have been studied, basic information on the impact of these practices on the natural productivity of the reservoir is lacking.

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Fish Yield Models for Thai Reservoirs

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Statistical relationships between fish yields and physical and environmental parameters for 17 Thai reservoirs were investigated. The relationship of fish yield to water surface area, watershed area, and mean depth was determined. Fish yield in relation to water inflow volume and water level during the rainy season in the previous year was investigated to develop a predictive model for fish catch in the following year in three separate reservoirs.

During the last three decades, 20 freshwater reservoirs, each with a surface area greater than 1 000 ha, have been built throughout Thailand. The creation of these reservoirs, with a total area of 285 272 ha, has provided a source of fish protein to the local people and a source of income from the sale of fish to nearby towns. After the rice-planting season, local farmers fish full-time, and continue part-time during the rice-growing season. Some of the farmers have adopted fisheries as their main occupational activity, although the combination of rice cultivation and fishing provides the local people with an opportunity to increase their yearly income and improve their standard of living.

Generally, reservoir fish production in Thailand has increased substantially compared with production from the more traditional riverine fishery (Sidthimunka 1972). However, it appears that most reservoirs have now reached their maximum production capacity. Fish production varies from year to year, and the degree of variation seems to be mainly related to fluctuating environmental conditions. The objectives of this study were to determine the relationships between fish yield and physical parameters to develop models to predict fish yield.

Materials and Methods

Fish catch records, 5 years after impoundment (Henderson et al. 1973), from reservoirs with surface areas greater 1 000 ha were used in this study (Table 1). When available, the averages for several years were used.

Multiple-regression analysis was used to develop an empirical statistical model to predict the yield of three reservoir fisheries using environmental factors that are thought to influence the yield.

Table 1. Physical parameters and fish yield in Thai reservoirs.

Reservoir	Surface area (ha)	Year of impoundment	Main objective	Height above MSL (m)	Mean depth (m)	Catchment area (km²)	Average annual catch at full water level	
							t/year	kg/ha
Northern								
Bhumipol	20 400	1964	Electricity	250	44.7	25 390	852.9	41.8
Sirikit	28 480	1972	Electricity	166	36.7	13 130	1 047.6	36.7
Kue lom	1 600	1972	Irrigation	285	4.5	2 700	148.0	92.5
Northeastern								
Ubolratana	41 000	1965	Electricity	182	6.2	12 160	2 274.0	55.4
Sirinthorn	29 200	1971	Electricity	142	5.1	2 100	1 277.2	43.7
Chulaporn	1 200	1972	Electricity	760	15.6	500	38.0	31.6
Nam Pung	1 920	1966	Electricity	254	8.6	300	131.0	68.2
Nam Oon	8 608	1973	Irrigation	186	6.4	1 100	211.4	24.5
Lam Takong	4 432	1968	Irrigation	280	15.5	1 340	100.0	22.5
Lam Pao	23 000	1968	Irrigation	162	5.5	5 950	1 514.9	65.8
Central								
Kang Kachan	4 960	1966	Irrigation	99	14.3	2 210	322.2	64.9
Pranburi	4 672	1976	Irrigation	60	10.0	3 030	190.2	40.7
Srinakarin	40 000	1979	Electricity	180	42.0	10 880	371.0	9.2
Krasiew	8 640	1980	Irrigation	92	5.0	1 220	425.0	49.1
Eastern								
Bang Pra	1 640	1975	Irrigation	30	7.0	130	48.5	29.6
Dok Grai	1 280	1975	Irrigation	50	5.2	13	99.1	77.4
Southern								
Bang Lang	5 120	1980	Electricity	110	31.5	2 080	54.9	10.7

Note: MSL = mean sea level.

Results

Relationship of Fish Yield and Physical Parameters

Using multiple regression analysis, the relationship between fish yield (*FY* in t), water surface area (X_1 in ha), catchment area (X_2 in km^2), and mean water depth (X_3 in m) was determined as:

[1] $FY = 327.65 + 0.03\,X_1 + 0.05\,X_2 - 30.78\,X_3$ ($r^2 = 0.87$; $p < 0.01$)

Table 2. Data on fish yield, water inflow, and water level from 1981 to 1987 in Sirinthorn, Kang Kachan, and Lam Pao reservoirs.[a]

	1981	1982	1983	1984	1985	1986	1987
Sirinthorn							
Inflow	270.00	304.33	235.25	448.50	246.00	—	—
Water level	140.34	140.45	139.73	140.50	140.00	—	—
Yield	—	387.64	476.83	685.41	1 277.27	720.11	—
Kang Kachan							
Inflow	184.50	168.00	85.75	112.25	201.25	112.21	—
Water level	97.80	96.80	89.80	92.60	98.70	92.60	—
Yield	—	322.21	148.62	412.99	214.16	192.08	200.09
Lam Pao							
Inflow	—	336.35	346.75	289.75	397.00	172.00	—
Water level	—	159.60	159.61	159.17	160.05	157.65	—
Yield	—	—	2 320.60	1 538.68	1 491.14	2 377.33	3 575.84

[a] Inflow (X_1) in 10^6 m^3; water level (X_2) in m above mean sea level; and yield (*FY*) in t.

Table 3. Aspects of the fishery of Sirinthorn, Kang Kachan, and Lam Pao reservoirs.

Reservoir	Year	Yield (kg/ha per year)	Main species
Sirinthorn	1981	22.1	Sardine-like fish, lipped mud carp, featherback
	1982	13.3	Sardine-like fish, lipped mud carp, featherback
	1983	16.3	Sardine-like fish, lipped mud carp, featherback
	1984	23.5	Sardine-like fish, lipped mud carp, featherback
	1985	43.7	Sardine-like fish, lipped mud carp, featherback
	1986	24.7	Sardine-like fish, lipped mud carp, featherback
Kang Kachan	1982	65.0	Barb, banded barb, river barb
	1983	30.0	Barb, river barb, banded barb
	1984	83.3	Barb, river barb, banded barb
	1985	43.2	Banded barb, river barb
	1986	38.7	Barb, banded barb, river barb
	1987	40.3	Barb, banded barb, river barb
Lam Pao	1982	100.9	Lipped mud carp, banded barb, sardine-like fish
	1983	66.9	Sardine-like fish, banded barb, lipped mud carp
	1984	64.8	Banded barb, lipped mud carp, sardine-like fish
	1985	103.4	Lipped mud carp, sardine-like fish, banded barb
	1986	155.5	Lipped mud carp, sardine-like fish, banded barb

Yield Models

Water inflow and the mean water level during the peak of the rainy season (August–November) and the fish yield for the different years are given in Table 2 for Sirinthorn (29 200 ha), Kang Krachan (4 960 ha), and Lam Pao (23 000 ha) reservoirs.

Present Fishery

Sirinthorn reservoir was impounded in 1971 and, since then, commercially valuable carnivorous fish, such as snakehead, have been overfished. Their stocks are now depleted, leaving only small-size fish such as the sardine-like fish (*Clupeichthys aesarnensis*), which is attracted to light and fished with scoop nets. The other species caught in quantity is the lipped mud carp (*Cirrhinus jullieni*), which is caught by gill net. The next most plentiful catch is the feather fish (*Notopterus notopterus*), which is caught by long-line and hook. The stocking program includes the stocking of Indian carp (*Labeo rohita*) and Nile tilapia (*Oreochromis niloticus).*

Kang Kachan reservoir was impounded in 1966 and Lam Pao reservoir 2 years later. They are rather old reservoirs and most high-priced fish (e.g., snakehead) are harvested by long-line and hook. Fish such as the barb (*Osteochilus hasselti*), lipped mud carp, and many other species of barb, all of which are herbivorous (Table 3), are found in these reservoirs.

The statistical relationships (multiple-regression analysis) of fish yield (in t) to water inflow of the previous year (X_1 in 10^6 m^3) and water level (X_2 in m above mean sea level (MSL)) for the three reservoir are:

Sirinthorn reservoir

[2] $FY = 95\,293.03 + 4.76\,X_1 - 648.62\,X_2\ (r^2 = 0.82)$

Kang Krachan reservoir

[3] $FY = 15\,919 + 13.13\,X_1 - 185.41\,X_2\ (r^2 = 0.60)$

Lam Pao reservoir

[4] $FY = 664\,515.6 + 39.59\,X_1 - 4\,236.15\,X_2\ (r^2 = 0.74)$.

Based on these relationships, the calculated yields for each year in the different reservoirs are given in Table 4. The deviation of the calculated yield from the actual yield was between 2.7% and 37.2%. Generally, the deviation of the predicted yield from the actual yield has decreased over the last 6 years. This is explained by the fact that the sample sizes have increased over the years.

Discussion

A model, designed to predict the average fish yield of new reservoirs in Thailand based on a physical parameter, was first attempted by Srisuwantach (1978). He correlated fish yield to mean depth in seven reservoirs. Bhukaswan and Pholprasith (1977) in their study on fish-yield prediction in Ubolratana reservoir

Table 4. Calculated annual fish yield (t) in three reservoirs based on the predictive models.

Reservoir	1982	1983	1984	1985	1986	1987
Sirinthorn	387.6	476.8	685.4	1 277.2	720.1	—
	(28.6)[a]	(22.9)	(9.6)	(3.0)	(14.3)	—
Kang Kachan	322.2	148.6	412.9	214.1	192.1	200.1
	(35.3)	(19.2)	(4.3)	(4.1)	(36.1)	(11.6)
Lam Pao	2 320.6	1 538.6	1 491.1	2 377.3	3 575.8	—
	(35.1)	(37.2)	(15.3)	(5.9)	(2.7)	—

[a] Values in parentheses are the percentage deviation of the calculated yield from the actual.

also used only one parameter (water level). In this study, two parameters (water surface area and watershed) were used to predict fish yields in the reservoirs.

Marshall (1982) attempted to predict fish yields in African reservoirs from preimpoundment physicochemical data. Hall (1985) considered water-level fluctuation to be an important parameter influencing fish yields in reservoirs. De Silva (1985) correlated the abundance of the exotic cichlid, *Sarotherodon mossambicus*, to fluctuation in water level in a Sri Lankan reservoir.

This study has shown that possible predictive models can be developed for reservoirs in Thailand, and perhaps elsewhere in Asia, using morphometric data and the influence of water-level fluctuations on fish yield. The next step would be to test the predictability and the applicability of these models, as well as similar ones, to reservoir fisheries management.

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Empirical Approaches for Evaluating Efficiencies of Different Fishing Methods in Tropical, Shallow Reservoirs: A Sri Lankan Case Study

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In most reservoir fisheries in the tropics, catch–effort data are not usually stratified according to fishing methods. This results in loss of precision in production estimates. In this paper, results of an analysis of monthly catch and effort data from May 1986 to February 1989 in two ancient reservoirs in Sri Lanka, Kaudulla (2 713 ha) and Minneriya (2 551 ha), are presented.

When the data were stratified according to fishing methods, the estimates of total fish production were improved. This is probably because some fishing methods, such as water beating (a modified gill-net fishing method to drive the fish toward nets) and beach seining, although practiced sporadically, show high efficiencies. The estimates of annual fish yields in Kaudulla and Minneriya are 192 kg/ha and 130 kg/ha, respectively.

A multiple-regression technique was used to analyze catch and effort data in the two reservoirs to evaluate the relative effectiveness of different fishing methods. On the basis of this analysis, it is concluded that gill netting would not have an adverse effect on fish stocks, at least over the range of fishing effort represented by the data and that, in Minneriya, beach seining seems to lead to diminished returns because it depletes stocks. The importance of this approach for the management of other reservoir fisheries in Asia is discussed.

One of the basic characteristics of artisanal fisheries is the multitude of fishing methods used (Kapetsky and Petr 1984; Bayley 1988; De Silva 1988a). Efficiencies of the different fishing methods vary (Fernando 1967; Marten 1979; Amarasinghe and Pitcher 1986; Bayley 1988). Generally, in production estimates, the differences in the efficiencies are not taken into account. This could result in a loss of precision in the estimates and make it difficult to deduce optimal fishing strategies. In this paper, an attempt is made to analyze catch and effort data in two Sri Lankan reservoirs to evaluate the relative efficiencies of different fishing methods.

The two ancient reservoirs that were studied, Kaudulla (8°10'N 80°55'E) and Minneriya (8°N 80°50'E), are 2 713 ha and 2 551 ha in surface area, respectively, and sustain artisanal fisheries. Some relevant morphometric and edaphic features of these reservoirs are summarized by De Silva (1988a). The fishing craft is non-mechanized outrigger canoe in both reservoirs, and the major gear is gill net. Mesh sizes range from 9 to 14 cm in Kaudulla (2–25 net pieces per craft) and from 7.5 to 11 cm in Minneriya (3–24 net pieces per craft). In both reservoirs, some people beat the water with wooden poles or weighted ropes from their craft to drive fish into the gill nets. Beach seines, which are illegal, are also sporadically operated in these two reservoirs. Beach seines are long panels (200 m) of nets of a single mesh size (7.5 cm). Cast nets (9.0-cm mesh size) are sporadically used in Kaudulla. The number of people fishing per craft in gill netting, water beating, and cast netting ranged from 1 to 3. Beach seines are operated by 5–12 people working from two craft.

Materials and Methods

Monthly catch and effort data were collected from the two reservoirs from May 1986 to February 1989 (in a few months sampling could not be carried out due to unavoidable circumstances). Each month, the two reservoirs were sampled for 3–4 days depending on availability of time and the intensity of the catch, and, at each sampling, over 60% of the craft were observed. Catch and effort data for each major species were collected separately for each fishing method.

The fishing methods are not simultaneously practiced in all months, and normal gill netting is the only regular fishing method in both reservoirs. Use of the other fishing methods is greatly influenced by factors such as water-level fluctuations and wind action. Beach seining is practiced during seasons with low water level, whereas water beating is less effective during windy periods. Beach seining and cast netting in Kaudulla are new developments that have appeared only since mid-1977, probably due to the increased demand for freshwater fish in the central province of the country.

In the ideal measure of fishing effort, employment of gear should directly reflect fishing mortality. Therefore, we considered that the expression of catch per unit effort (CPUE) for any of the fishing methods in the two reservoirs is the "catch per net per haul per day." In normal gill netting, this CPUE value is essentially equal to catch per net piece-day because there is only one haul per day. These CPUE values for each fishing method were compared with other expressions of CPUE (i.e., catch per net-day, catch per person-day, and catch per craft-day) using pair-wise parametric correlation.

The uniformity of the distribution of CPUE occurs only within a species; therefore, the estimation of total fish production using CPUE and total effort for individual species can be estimated separately. Monthly fish production for the two major cichlid species (*Oreochromis mossambicus* and *O. niloticus*) in both reservoirs were calculated for the data stratified according to fishing methods, and without stratification. Because these two cichlid species form the major portion of the catch (over 90% in Kaudulla and over 80% in Minneriya), total fish production was computed from these estimates using the percentage contribution of the two cichlid species (assuming all other species to have similar catchabilities).

Length measurements of *O. mossambicus* and *O. niloticus* for different fishing methods in each reservoir (made during a simultaneous study) were also used in this analysis. However, length–frequency data of the two cichlid species in normal gill netting and water beating could not be obtained separately for the two fishing methods.

A curvilinear multiple regression technique was employed to evaluate the relative effectiveness of different fishing methods. The multiple regression equation was forced to go through the origin (Zar 1974) and was in the following form:

$$[1] \quad Y = \sum_i a_i f_i + \sum_i b_i f_i^2 + \sum_i \sum_j c_{ij} f_i f_j$$

where Y = yield (per ha per month) and f_i = fishing effort (per ha) (i.e., fishing intensity) per month for gear i. The regression coefficients of the linear terms (a_i) in this multiple-regression equation reflect the contribution of each fishing method to total yield. When the linear term is positive, the coefficient of the negative square term (b_i) indicates how quickly increased fishing effort leads to diminished returns due to reduced stocks. Cross-product terms (c_{ij}) indicate the interaction between fishing gears.

Because there were only 29 observations in Kaudulla and 28 in Minneriya, effort data on the fishing methods that possibly have similar influences on fish stocks were combined to reduce the number of independent variables.

Results

Monthly CPUE expressed as catch per craft-day for each fishing method for all species are given in Fig. 1, and indicate the need for stratification according to fishing methods. Correlation coefficient matrices of the pair-wise comparisons of CPUE for Kaudulla and Minneriya are given in Table 1. The most appropriate measure of CPUE can be selected by eliminating one member of the pairs with consistently high correlations, and picking up the measure of CPUE for which effort data can be more conveniently collected. All the CPUE comparisons for the different fishing methods in both reservoirs were significant at least at the 95% level (Table 1). Catch per craft-day, being the most convenient, was used to estimate total fish production. Catch per craft-day also enables comparison to be made with other reservoirs.

Total monthly fish yields of *O. mossambicus* and *O. niloticus* in the two reservoirs, estimated from the data stratified according to fishing methods and from nonstratified data, are given in Table 2. In Kaudulla, of the 29 months sampled, lower or equal coefficients of variation (COV) in stratified estimates were obtained in 22 months for *O. mossambicus* and 20 months for *O. niloticus* compared with nonstratified estimates. In Minneriya, out of the 28 months sampled, in 16 instances for *O. mossambicus* and in 20 instances for *O. niloticus*, lower or equal COV were obtained in stratified estimates compared with nonstratified estimates. Based on this analysis, total annual fish yields in Kaudulla and Minneriya during 1986–1989 were estimated to be 192 kg/ha and 130 kg/ha, respectively.

The size range of fish exploited by normal gill netting is essentially the same as the size range exploited by water beating because both fishing methods rely on gill nets of similar mesh sizes. Therefore, using the standardization procedure described below, effort data for these two fishing methods were combined.

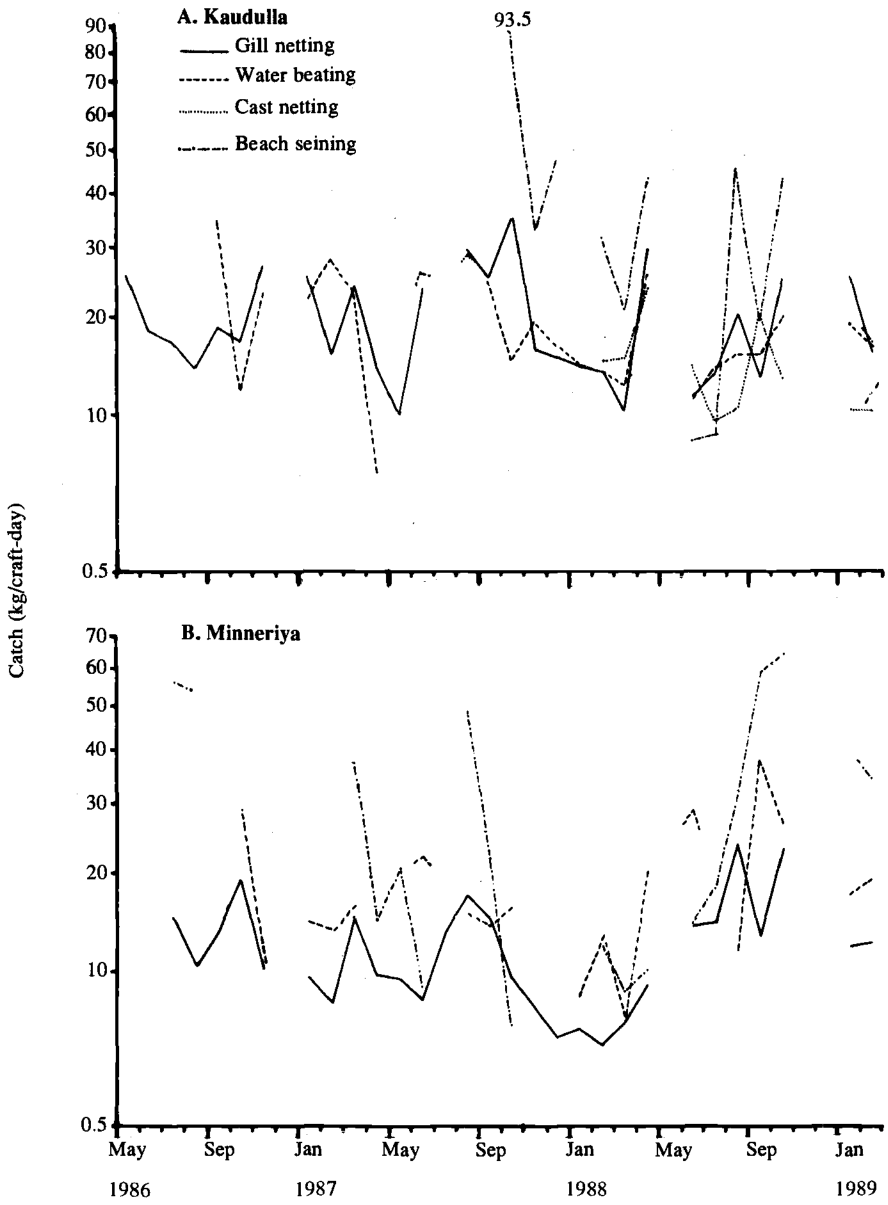

Fig. 1. Monthly catch (kg) per craft-day of all species in different fishing methods in (A) Kaudulla and (B) Minneriya. No sampling was carried out in May and June 1986 in Minneriya, in July 1987 in Kaudulla, and in December 1986 and May, November, and December 1988 in both reservoirs. Note that gill netting is the only regular fishing method in both reservoirs.

In Kaudulla, size–frequency distributions of *O. mossambicus* and *O. niloticus* in cast-net catches and beach-seine catches were similar (Fig. 2; Table 3). The fishing effort of cast netting was, therefore, standardized using the ratio of the mean CPUE

Table 1. Pair-wise comparisons of different measures of CPUE in Kaudulla and Minneriya using correlation coefficients: a = catch per boat-day; b = catch per person-day; c = catch per net-day; d = catch per net per haul per day. All comparisons are significant at least at the 95% level.

Species / fishing method		Kaudulla a	Kaudulla b	Kaudulla c	Minneriya a	Minneriya b	Minneriya c
O. mossambicus							
Gill netting	b	0.99			0.99		
	c	0.96	0.95		0.97	0.96	
Water beating	b	0.98			0.99		
	c	0.97	0.96		0.92	0.93	
	d	0.92	0.86	0.85	0.60	0.59	0.66
Beach seining	b	0.99			0.99		
	d	0.89	0.87		0.95	0.89	
Cast netting	b	0.99					
O. niloticus							
Gill netting	b	0.99			0.99		
	c	0.90	0.90		0.95	0.93	
Water beating	b	0.92			0.99		
	c	0.89	0.80		0.88	0.88	
	d	0.66	0.48	0.73	0.67	0.67	0.66
Beach seining	b	0.98			0.96		
	d	0.92	0.87		0.89	0.76	
Cast netting	b	0.96					
All species							
Gill netting	b	0.99			0.99		
	c	0.90	0.90		0.95	0.93	
Water beating	b	0.98			0.99		
	c	0.86	0.83		0.86	0.87	
	d	0.69	0.59	0.74	0.55	0.54	0.60
Beach seining	b	0.98			0.95		
	d	0.92	0.87		0.88	0.74	
Cast netting	b	0.96					

of cast netting to the mean CPUE of beach seining (Table 4), and the total effort values for the two fishing methods were obtained by adding these standardized cast-net effort values to the effort values of beach seining in each month in Kaudulla.

In Kaudulla, CPUE values of normal gill netting and water beating were more or less similar (Fig. 1; Table 4); whereas, in Minneriya, the mean CPUE of water beating was about 1.5 times higher than the CPUE of normal gill netting (Table 4). Effort values of normal gill netting and water beating were simply added in Kaudulla; whereas effort values of water beating in Minneriya were standardized in comparison with normal gill netting by dividing by 1.5. These values were

Table 2. Monthly yield estimates (t) for *O. mossambicus* and *O. niloticus* in Kaudulla and Minneriya, calculated using data stratified according to fishing methods (S) and nonstratified data (NS). The coefficient of variation (COV) corresponding to each estimate is given in parentheses. COV calculated according to the method of Caddy and Bezigos (1985).

	Kaudulla				Minneriya			
	O. mossambicus		*O. niloticus*		*O. mossambicus*		*O. niloticus*	
Month	S	NS	S	NS	S	NS	S	NS
May 1986	21.5 (11.8)	21.5 (11.8)	22.4 (12.0)	22.4 (12.0)	—	—	—	—
Jun	14.0 (10.2)	14.0 (10.2)	16.9 (12.8)	16.9 (12.8)	—	—	—	—
Jul	4.1 (20.9)	4.1 (20.9)	15.5 (20.2)	15.5 (20.2)	22.3 (13.3)	22.2 (14.4)	11.6 (15.2)	16.0 (25.6)
Aug	9.4 (15.2)	9.4 (15.2)	16.2 (8.2)	16.2 (8.2)	18.7 (13.8)	18.3 (13.6)	3.4 (22.6)	3.8 (23.6)
Sep	4.8 (14.1)	4.9 (23.4)	31.7 (9.5)	31.5 (14.6)	18.8 (11.4)	18.1 (11.9)	9.4 (9.1)	9.4 (13.6)
Oct	4.1 (9.8)	4.1 (10.1)	30.6 (9.2)	30.5 (9.5)	31.7 (15.1)	30.6 (14.7)	17.1 (17.5)	16.6 (19.0)
Nov	11.8 (13.0)	11.8 (15.4)	40.5 (11.2)	40.6 (10.9)	13.7 (8.9)	13.7 (9.0)	10.7 (9.0)	10.7 (9.4)
Jan 1987	5.7 (8.7)	5.7 (11.6)	35.0 (7.5)	35.1 (7.5)	10.9 (17.7)	10.9 (18.0)	14.7 (13.0)	14.7 (13.3)
Feb	6.3 (13.0)	6.3 (17.6)	40.0 (10.9)	40.1 (13.6)	21.1 (13.5)	22.1 (15.1)	8.3 (6.6)	13.1 (52.0)
Mar	12.2 (12.2)	12.2 (13.1)	65.5 (16.1)	65.5 (15.7)	18.9 (23.0)	20.7 (22.6)	19.1 (44.6)	31.7 (39.7)
Apr	4.2 (13.6)	4.2 (14.5)	19.7 (10.5)	19.7 (10.9)	14.0 (13.3)	17.0 (11.2)	3.7 (5.3)	3.3 (10.0)
May	4.0 (10.5)	4.0 (11.2)	13.2 (10.0)	13.2 (10.3)	13.9 (26.2)	15.4 (25.4)	8.9 (37.2)	11.7 (34.8)
Jun	3.6 (14.6)	3.6 (14.6)	33.2 (12.2)	33.2 (12.2)	6.0 (44.4)	6.0 (12.6)	6.3 (12.6)	6.3 (15.1)
Jul	—	—	—	—	22.4 (12.2)	23.2 (15.8)	8.4 (8.5)	9.8 (40.5)
Aug	14.9 (12.2)	14.8 (12.4)	37.0 (9.1)	37.6 (11.5)	11.2 (12.0)	12.0 (11.0)	7.2 (18.0)	9.3 (21.2)
Sep	10.8 (11.8)	10.9 (12.5)	35.8 (8.9)	35.7 (8.9)	13.8 (10.6)	13.4 (9.7)	3.4 (3.2)	3.5 (8.8)
Oct	15.1 (7.3)	16.0 (7.6)	78.7 (8.3)	91.5 (9.6)	13.2 (8.5)	12.9 (8.8)	3.2 (9.8)	3.2 (9.7)
Nov	8.1 (10.6)	8.0 (9.7)	31.8 (11.0)	36.3 (10.8)	12.6 (14.5)	12.1 (16.1)	2.6 (21.2)	2.5 (22.4)
Dec	5.1 (11.8)	6.3 (10.1)	29.0 (10.0)	43.4 (11.3)	6.6 (9.6)	6.6 (9.6)	0.5 (20.3)	0.5 (20.3)

Jan 1988	5.7 (16.0)	5.7 (15.8)	23.5 (7.6)	23.5 (7.6)	8.5 (12.5)	11.2 (16.3)	1.0 (16.2)	1.5 (20.4)
Feb	6.7 (9.9)	6.2 (14.4)	38.3 (8.5)	39.6 (9.2)	10.2 (14.3)	10.9 (15.2)	2.4 (14.3)	2.6 (16.2)
Mar	7.7 (16.6)	6.1 (15.3)	25.4 (9.4)	29.6 (9.3)	9.6 (13.5)	8.6 (9.9)	3.1 (13.6)	4.5 (13.9)
Apr	11.6 (8.6)	10.3 (7.3)	65.0 (7.2)	76.5 (7.0)	8.8 (9.8)	9.0 (10.1)	7.6 (9.9)	7.7 (10.9)
Jun	2.5 (7.8)	2.5 (7.7)	11.1 (8.9)	10.9 (7.5)	23.6 (8.6)	23.7 (7.8)	7.3 (7.7)	7.3 (7.5)
Jul	3.6 (16.2)	3.7 (16.2)	16.0 (9.7)	16.1 (9.7)	22.0 (15.1)	23.1 (12.1)	6.6 (14.1)	7.8 (13.1)
Aug	8.8 (10.9)	7.7 (8.3)	52.6 (10.9)	47.1 (8.0)	35.2 (10.1)	34.5 (10.2)	14.3 (20.6)	16.2 (21.2)
Sep	6.8 (8.9)	6.6 (9.1)	27.8 (6.0)	30.2 (5.9)	26.1 (13.3)	28.2 (17.1)	9.6 (17.4)	10.1 (17.8)
Oct	9.8 (14.7)	10.0 (15.6)	52.1 (13.1)	60.1 (13.9)	42.4 (12.8)	45.8 (13.6)	9.8 (13.1)	10.7 (14.5)
Jan 1989	6.3 (9.1)	6.5 (10.4)	29.3 (8.7)	29.6 (9.0)	19.7 (8.4)	19.9 (9.1)	8.3 (8.8)	8.3 (8.7)
Feb	8.5 (8.0)	7.2 (8.6)	28.3 (7.6)	29.1 (7.1)	26.9 (15.7)	28.6 (15.1)	15.2 (23.9)	18.6 (22.8)
Annual	98.4	96.6	398.1	421.1	215.7	222.2	96.0	112.0

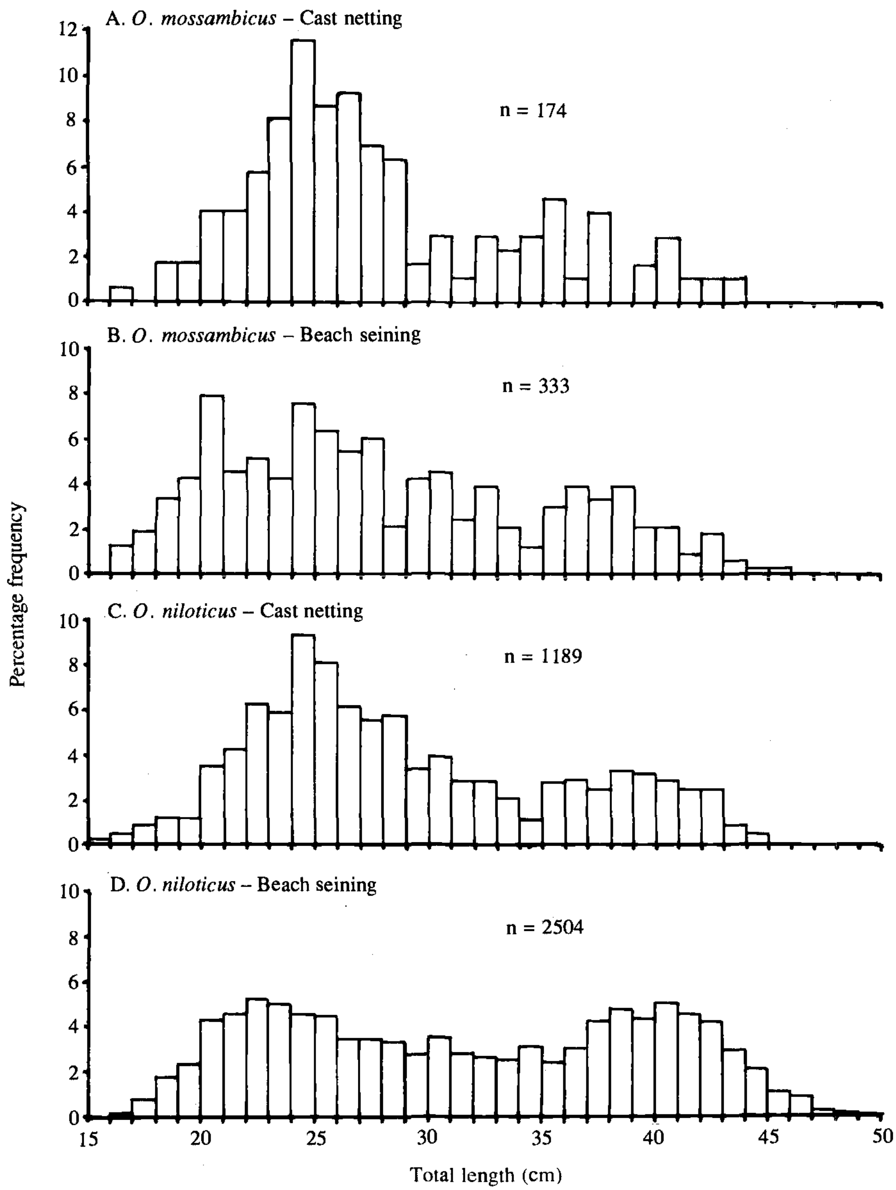

Fig. 2. The size-frequency distributions of *O. mossambicus* and *O. niloticus* caught in cast nets and beach seines in Kaudulla.

subsequently added to the effort of normal gill netting to obtain the total effort of gill netting and water beating.

The curvilinear multiple regression equations fitted for yields (kg/ha per month) of all species (*Y*) and for the fishing intensity of different fishing methods in the two reservoirs:

Table 3. Mean total length (cm) of *O. mossambicus* and *O. niloticus* caught by various fishing methods in Kaudulla and Minneriya during 1986–1989 (ranges are given in parentheses).

Reservoir/species	Gill netting and water beating	Cast netting	Beach seining
Kandulla			
O. mossambicus	24.9	28.1	28.1
	(15–44)	(16–44)	(16–46)
O. niloticus	25.9	29.2	31.6
	(14–48)	(15–48)	(15–50)
Minneriya			
O. mossambicus	22.1	—	21.3
	(13–38)		(14–38)
O. niloticus	22.2	—	23.3
	(15–42)		(14–46)

Table 4. Mean catch per unit effort (kg per craft-day) of all species caught by various fishing methods in Kaudulla and Minneriya during 1986–1989.

	Kaudulla	Minneriya
Gill netting	19.79	12.00
Water beating	18.96	18.15
Cast netting	15.92	—
Beach seining	34.55	27.70

Kaudulla

[2] $Y = 17.7731 f_1 - 19.4183 f_2 + 3.9689 f_1^2 + 202.8187 f_2^2 + 25.9011 f_1 f_2$
$(r^2 = 0.916)$

Minneriya

[3] $Y = 8.4924 f_1 + 63.2329 f_2 + 3.9688 f_1^2 - 392.1433 f_2^2 + 70.6734 f_1 f_2$
$(r^2 = 0.896)$

In these equations, all the fishing intensity values are in number of craft per hectare per month and f_1 and f_2 represent the fishing intensity for gill netting and beach seining, respectively.

When the regression coefficients of these equations are considered, it is evident from the coefficients of the linear terms, that the contribution of beach seining to the total yield in Minneriya is very high and that an increase in beach seines would lead to diminished returns (higher coefficient of negative square terms) through depletion of stocks. Gill netting seems to have no adverse effect on the stocks at least within the range of fishing effort considered in this study. A similar interpretation of multiple regression is found in Marten (1979).

In Kaudulla, however, the regression coefficients do not clearly show the relative effectiveness of different fishing methods. This may suggest that this method of analysis is not applicable to the fishery of Kaudulla.

Discussion

The efficiencies of the other fishing methods are appreciably higher than normal gill netting (Fig. 1). Therefore, although practiced sporadically, the total fish yield estimates are influenced considerably by the seasonal variation in the fishing intensities of the different gear. Stratified random sampling according to fishing methods (Caddy and Bazigos 1985) is, therefore, necessary for more precise estimates of total fish production. The differences in fishing mortality due to various fishing methods could be expected and would probably require the determination of the optimal combination of different fishing methods.

The multiple-regression technique employed in this study, which is similar to the approach adopted by Marten (1979) for the inshore fishery of Lake Victoria (East Africa), is useful for evaluating the relative efficiencies of different fishing methods when the available data are limited.

There are some limitations in the regression approach used in this study. The results can be biased by unknown factors such as seasonal variations in biological productivity and water-level fluctuations, which are correlated with the measured variables and fish population density. Perhaps the major limitation in this analysis is that fish yields are assumed to be the consequence of the long-term intensities of different fishing methods. Because of these limitations, the results of this analysis permit only a relative interpretation.

As indicated in this study, an increase in beach seining in Minneriya would lead to diminished returns, possibly through depletion of stocks. A reason for these diminished returns, in addition to high fishing mortality caused by beach seining, may be that the reproductive behaviour of the cichlid species may be interrupted. Evidently, an increase in gill netting does not decrease the yield within the range of fishing effort considered in this study.

This method of analysis does not seem to be fully applicable to the fishery of Kaudulla. Unlike in Minneriya, where beach seining has been practiced since the late 1950s (Fernando 1967), less selective fishing methods are new developments in Kaudulla. Therefore, the fishery may not be in equilibrium, and the multiple-regression approach may not be applicable. It may also be possible that, as indicated by the positive square terms in the multiple-regression equation, all the fishing methods in Kaudulla are, at present, at a suboptimal level. In Kaudulla, submerged tree stumps provide refuge for fish and prevent intensive exploitation of fish stocks.

The present analysis gives an alternative method of analyzing catch data. It would be useful to attempt this method of analysis for the reservoir fisheries in other parts of Asia.

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Discussion: Section 3 — Management and Modeling

It was pointed that three significant advances in reservoir fisheries management have been made in some Asian countries. These are:

- Management based on a classification that takes into account reservoir size, storage volume, or trophic status;
- Adoption of a realistic stocking program that takes into account the choice of species based on limnological conditions, food resources, availability of vacant niches, and population dynamics and species interactions; and
- Due consideration for fishery practices, particularly with respect to yield-enhancing techniques adopted for small-sized reservoirs, that could bring about adverse effects on the environment.

The discussion focused on the need to develop models for fish-yield prediction, as well as for stock and recapture fisheries. At present, such work on Asian reservoirs is very limited, and the models that are available have not been validated. The influence of water-level fluctuations on fish yield was brought to focus and, here again, the limited number of studies on Asian reservoirs do not permit generalizations to be made. However, this was recognized as an area where time-lapse modeling could be attempted on the available information. It was felt that, in most countries in Asia, there is a considerable volume of data available but, because of inadequate training in modeling techniques, the data remain underutilized.

The Chinese model of integrated management of the reservoir water, along with the catchment and downstream areas, was appreciated. Possibilities of direct transfer of this technology to other countries was discussed. The consensus was that the social system in China permits such integration and that it might be difficult to transplant such a system to other countries where there is individual ownership of land around the reservoirs. Nevertheless, as the catchment area of reservoirs in most countries is government owned, and managed by reservoir authorities, a certain degree of integration remains possible and should be investigated on a pilot scale.

Asian reservoir fisheries, by and large, are artisanal. Reservoirs are located in rural areas and provide employment opportunities and an inexpensive source of animal protein to poor sectors of the communities in the vicinity of the reservoirs. Therefore, it was felt that social aspects of the fisheries have a direct bearing on its management. In fact, it was pointed out that people who fish should be involved in management decisions, such as limitations on fishing effort and enforcement of closed seasons and areas. However, the research effort expended on the socioeconomic aspects of Asian reservoir fisheries is scanty. Therefore, socioeconomic studies should be encouraged, and reservoir fishery scientists should work in close collaboration with sociologists.

Section 4 —
Culture Techniques

Nile Tilapia Culture in Net Cages in a Chinese Reservoir

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*Experiments were conducted with Nile tilapia (*Oreochromis niloticus*) in net cages in reservoirs from 1984 to 1988. Results indicate that it is best to lay net cages in the fertile zone in a reservoir and to stock wintering fingerlings. Daily weight gain (*DG*), harvesting weight (*HW*), and weight gain times (*WT*) (ratio of harvesting to stocking sizes) were related to size at stocking (*SS*). The relationships are* DG = *1.04 + 0.028* SS, HW = *146.52 + 4.22* SS, *and* WT = *42.32* $SS^{-0.43}$. *It was advantageous to stock at a density of 150–160 fish/m² using 20–30 g wintering fingerlings.*

Nile tilapia is cultured in high-yield fish ponds in Jiangsu Province. Tilapia was introduced into reservoirs only relatively recently. Experiments were conducted on net cage culture from 1984 to 1988 to improve population structure of the cultured fish, extend the water area under culture, and raise fish production in the reservoir. At the same time, a series of studies on the culture of Nile tilapia in reservoirs was undertaken. The results of these experiments are presented in this paper.

Materials and Methods

The experiments were conducted in Wagou reservoir in 1984–1985 and in Shishantou reservoir in 1985–1988. Fingerlings of Nile tilapia were purchased from Nanjing Fisheries Seed Multiplication Farm. Fingerlings of 2.7–7.1 g were stocked in 1984 and 1985. The stocking densities used in triplicate for each treatment were 100 and 140 fish/m². Wintering fingerlings of 15.6–22.7 g, at stocking densities of 79 and 114 fish/m², were replicated six and nine times, respectively, in 1986. The fingerling size and stocking densities were improved to 29 and 35 g with three replications for each treatment at 114 and 200 fish/m², respectively, in 1987. Fingerling sizes were continuously increased to 48.5, 77.3, and 96.2 g with three replications for each treatment at stocking densities of 150–160 fish/m² in 1988. Fingerlings were stocked when water temperature was 16–18°C.

All experiments were carried out in net cages made of polyethylene net (mesh size 1.5 cm). Cages were 7 × 4 × 2.3 m, with covers (3-cm mesh). The frames were made of bamboo in 1984–1985 and fixed piles in 1986–1988. The cages were arranged in a triangle with 15–20 m between each cage; 2 m of the cages were under water. To prevent loss of feed, 4 × 4 m of plastic film was set on the bottom of each cage.

Paste feed, such as rapeseed cake and rice bran, was used in 1984 and 1985. Pelleted diet 8602 with 29.12% crude protein was used from 1986. Feeding rates were 5–7% of body weight in May and June and 4–5% of body weight between July and October. Fish were fed three times per day, morning (0800–0900), noon (1300–1400), and evening (1800–1900). Duckweed or fermented grass was added once a day from July at 10% of body weight.

Sampling was carried out monthly to determine body length and weight. Plankton biomass was measured once a month. Dissolved oxygen was measured using a model CS-4A DO meter, and the transparency by a Secchi disk.

Results and Discussion

Cages were put in open-water areas, near the dam in areas with about 60 cm Secchi disk visibility, and fertilized coves with about 35 cm visibility. There were significant differences in the growth of Nile tilapia among the areas (Table 1). For example, tilapia in cage 1, located in a fertilized cove, grew faster than those in cage 5, located in an open-water area near the dam, until July. When the position of the two cages was interchanged, the growth of tilapia to the end of August was reversed. When the experiment was terminated in October, the average body weight was 68.2 g in cage 1 and 73.8 g in cage 5. The results indicate that natural food may have enhanced the growth and that its role cannot be ignored in cage culture with artificial feeding. Different areas in the reservoirs had different fertility. Net cages should be located in areas of high fertility or near the inflow of domestic animal wastes to obtain better fish growth.

Fingerlings of 2.7 g and 7.1 g, nursed in ponds, were stocked in 1984 and 1985, respectively. Because of the short period of growth (about 130 days), the stocking of small fingerlings resulted in small size at harvest. Therefore, the yields per unit area were lower than 75 t/ha, with a harvested weight of 50–70 g in the first 2 years. These results enabled us to plan our experiments in more detail in later years.

Starting in 1986, the size of fingerlings that were stocked was changed from

Table 1. Growth of *O. niloticus* in cage 1 and cage 5 located in different areas of Wagou reservoir in 1984.

	Cage 1		Cage 5	
Date	Weight (g)	Daily gain (g)	Weight (g)	Daily gain (g)
28 June	2.7	—	2.7	—
28 July	27.3	0.82	11.7	0.30
28 August	45.3	0.58	38.7	0.87
4 October	68.2	0.62	73.8	0.95

nursing fingerlings to wintering fingerlings of 15–35 g. The harvested weight was 231 g, with a daily weight gain of 1.52 g and a 11.2-fold increase for a 134-day culture period in 1986. When stocking size was increased to 28–35 g in 1987, the harvested weight increased to about 300 g, with a daily weight gain of 2.10 g and a 9.1-fold increase in 129 days of culture. In 1988, fingerling size was further increased to 48.5, 77.3, and 96.2 g and the harvested sizes were 375, 502, and 535 g, respectively. The daily weight gains were 2.55, 3.32, and 3.50 g, respectively. These results show that the larger the stocking size, the higher the daily weight gain (Table 2).

Size of stocking was positively linearly correlated to daily weight gain (Fig. 1). The regression equation was:

[1] $DG = 1.04 + 0.028\ SS$ ($r = 0.94$; $n = 20$; $p < 0.01$)

where SS = fingerling size stocked (g), and DG = daily weight gain (g).

The size of fingerlings at stocking was curvilinearly related to ratio of final to initial weights (WT) (Fig. 2) and the relationship was:

[2] $WT = 42.32\ SS^{-0.43}$ ($r = -0.97$; $n = 20$; $p < 0.01$).

The harvested size of tilapia is related to economic benefits. The size at stocking was linearly related to harvested size (HW) (Fig. 3). The regression equation was:

[3] $HW = 146.52 + 4.22\ SS$ ($r = 0.96$; $n = 20$; $p = < 0.01$).

Table 2. Relationship between stocking size and daily weight gain, harvested weight, and relative increase in weight.

Size at stocking (g)	Feed	Harvested weight (g)	Average daily gain (g)	Ratio of final to initial weight
2.7	rape seed cake	58.1	0.43	21.52
7.1	rape seed cake	118.6	0.82	16.7
15.6	diet 8602	215.3	1.35	13.8
15.6	diet 8602	220.9	1.45	14.16
15.6	diet 8602	225.0	1.55	14.42
15.6	diet 8602	239.9	1.62	14.93
15.6	diet 8602	233.0	1.65	14.94
22.7	diet 8602	241.2	1.77	10.63
22.7	diet 8602	248.3	1.87	10.94
22.7	diet 8602	261.8	1.90	11.53
22.7	diet 8602	263.7	1.98	11.62
29.0	diet 8602	295.0	2.06	10.17
35.0	diet 8602	315.0	2.17	9.00
35.0	diet 8602	317.0	2.19	9.06
48.5	diet 8602	358.9	2.45	7.40
48.5	diet 8602	374.9	2.55	7.73
77.3	diet 8602	438.3	3.2	5.67
77.3	diet 8602	501.9	3.32	6.49
96.2	diet 8602	519.5	3.43	5.40
96.2	diet 8602	534.9	3.50	5.56

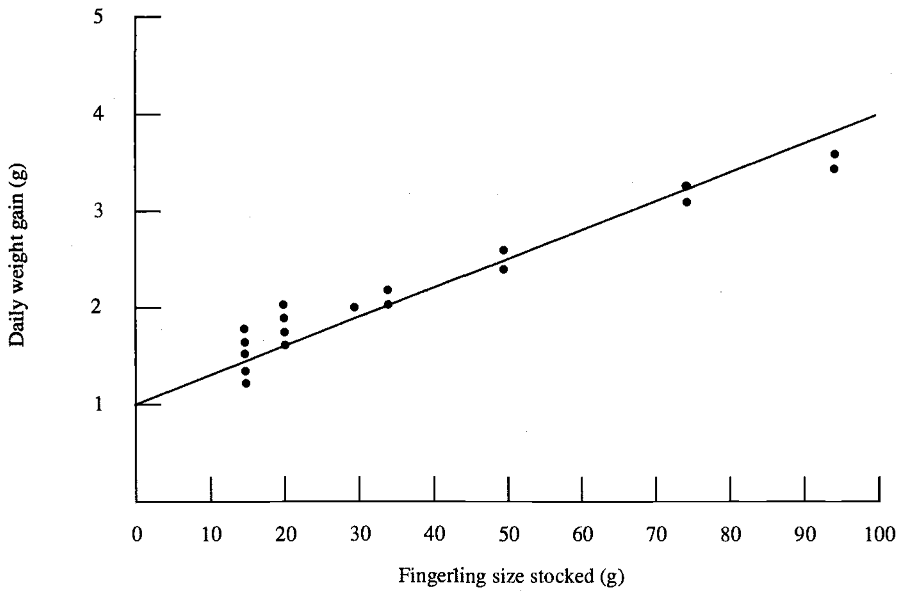

Fig. 1. Relationship between fingerling size stocked and daily weight gain.

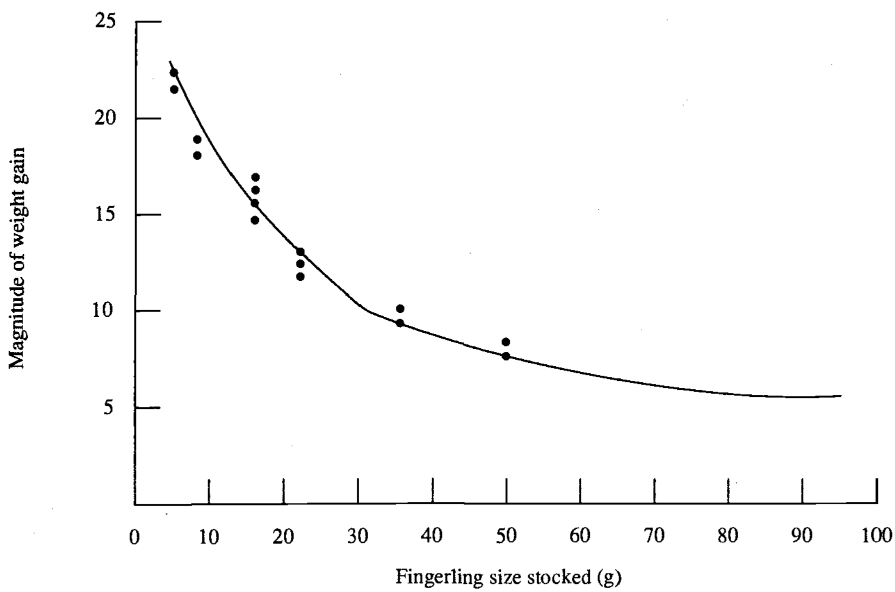

Fig. 2. Relationship between fingerling size stocked and the increase in weight.

Harvested weight and weight-gain rate regressions were derived when size of stocking was known, which provided useful information for planning. The experiments showed that if stocking density was reasonable, a harvested size of 250 g, the most desired market size, could be reached with 10-fold weight-gain rates when wintering fingerlings between 20 and 30 g are stocked. The last

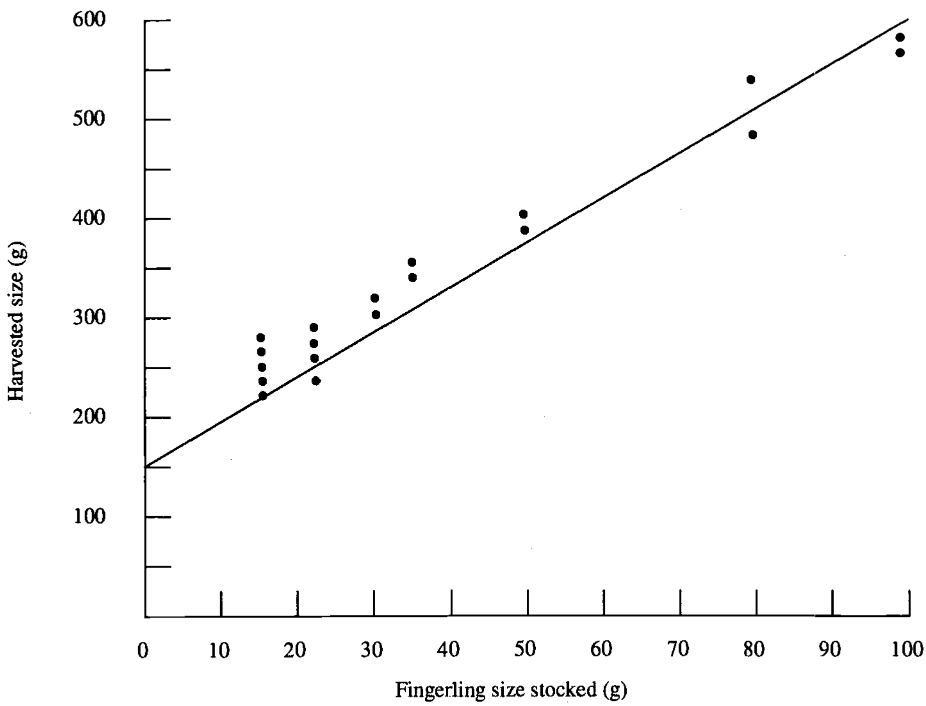

Fig. 3. Relationship between fingerling size stocked and harvested size.

equation indicates that an increase of one unit of weight at stocking increases the weight at harvest by 4.22 units.

The results of experiments from 1984 to 1988 show that it is not desirable to stock juvenile fingerlings because of small net weight gain, low economic return, and low yield. If the stocking size is greater than 50 g using wintering fingerlings, large harvest size and high economic benefits can be obtained. However, it is difficult to get sufficient numbers of large-size wintering fingerlings and fingerling farming is not economic. Stocking with 20–30 g wintering fingerlings provided good results when harvest weight and market needs were considered.

From the experiments from 1984 to 1985, paste feeds, such as rapeseed cake, rice, and wheat bran, which had high losses and low feed efficiency, were used in tilapia cage culture. In 1986, a new pelleted diet (8602) was compounded (12.76% moisture, 29.12% crude protein, 5.68% crude fibre, 5.97% crude fat, 7.84% ash, 35.98% nitrogen-free extract, 1.01% calcium, 1.12% phosphorus, and 0.52% NaCl).

An experiment was conducted to compare diet 8602 with a rapeseed-cake control diet. Five net cages were used. All cages had the same stocking density and were located in the same water area. The experiment was started on 13 July.

The results (Table 3) indicate that the growth rate of fish fed diet 8602 was higher. When fish were harvested on 4 October, individual weights in the experimental cages averaged 227.9 g, 16.4% higher than in the control cage (195.8 g). Tilapia produced in the experimental cages had a normal form. Those

Table 3. Growth of fish fed rapeseed cake (control) and diet 8602 (experimental).

Cages	Fish body weight (g)			
	13 July	18 August	17 September	4 October
Control	71.4	111.1	163.9	195.8
Experimental	67.7	117.8	210.6	227.9

produced in the control cage, however, had an expanded abdomen, a short and thick abnormal body form, and a higher percentage of fat in the internal organs.

Stocking density experiments were conducted with 79–114 fish/m^2 in 15 cages in 1986. The total yields from the two cages with the highest stocking density (114 fish/m^2) were highest. The average harvested weight was 245.6 g in the three cages with the lowest stocking density, and 233.5 g in the other three cages.

To determine the optimum stocking density and to evaluate whether dissolved oxygen had a relative influence at high stocking densities, dissolved oxygen concentrations were determined regularly under different weather conditions and at different water depths both inside and outside of cages with the highest stocking density (200 fish/m^2). Data from 460 measurements confirmed that the dissolved oxygen concentration at 2-m depth of water inside the cages was about 3 mg/L, and was not limiting tilapia growth. Size at stocking was further increased to 48.5–96.2 g with 160 fish/m^2 of stocking density (150 fish/m^2).

Because large fingerlings were stocked at a reasonable density, the daily gain was high. After 128 days of culture, body weight at harvest was 374.9 g (from 48.5 g stocking size), and 501.9 and 534.0 g from 77.3 and 96.2 g stocking size, respectively. The highest yield was 65.8 kg/m^2 when stocking size was 96.2 g. Selling price was 6.00 CNY/kg fish, with a profit of 2.01 CNY/kg fish (1 USD = 4 CNY) because of the large harvest size and high quality. Experiments on stocking density for 4 years showed that the stocking density of tilapia should be higher than 150 fish/m^2 if high yields are to be achieved. Because tilapia have a short growth period, large stocking size is a decisive factor.

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Tilapia Cage Culture in Reservoirs in Northern China

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*Since 1985, high-yield cage culture techniques for tilapia (*Oreochromis niloticus*) in Jindou reservoir, Shandong Province, northern China, have been studied. Stocking size, stocking density, diet ingredients, feeding rate, and effects on survival of water temperature differences between cages and nursing ponds during stocking were studied. The optimum stocking density was 300–400 fish/m^2 (30–50 g/fish), and the best feeding rate was 3–4.5% of body weight per day. At stocking, the water temperature should be 20 °C or higher. The average yield was 100.6 kg/m^2; the highest was 242.5 kg/m^2. The average food conversion ratio was 1.9; the best was 1.3.*

Cage culture experiments with tilapia (*Oreochromis niloticus*) were carried out in Jindou reservoir, Shandong Province, northern China, to develop tilapia cage-culture techniques that could be adopted in northern China. The main aims of the experiments were, first, to study the effects of stocking size, stocking density, and different diet ingredients and feeding rates on fish growth and yield; and, second, to determine the effects of differences in water temperature during stocking on fish survival.

Materials and Methods

Experimental Location

Experiments (six trials) were carried out in Jindou reservoir (35°38′–36°17′N; 117°14′–117°59′E). This reservoir has a catchment area of 87 km^2, a fish culture area of 200 ha, a water storage capacity of 3.5×10^6 m^3, and an average depth of 6–8 m. Cage sizes were $2 \times 2 \times 2$ m, $2.5 \times 2.5 \times 2.5$ m, $3 \times 3 \times 3$ m, $3.5 \times 2.5 \times$

2.5 m, and 4 × 4 × 2.5 m. The cages had bamboo frames; however, steel bars (12-mm diameter) were used for the bottom frame and acted as sinkers. Each cage was covered with a net.

Tilapia fingerlings were obtained from overwintering ponds that were heated by waste water from a power station.

Environmental Conditions

Water quality and plankton biomass from June to September 1987 are summarized in Tables 1–2. The dissolved oxygen (DO) content outside and inside the cages was the same (over 9 mg/L) in June but, from July to August, DO in open waters was 4.6–5.8 mg/L and was even lower in the cages; Secchi disk transparency was 76–177 cm outside and 68–98 cm inside the cages; mineral nitrogen was 0.063–4.593 mg/L outside and 0.154–6.919 mg/L inside the cages; phosphate was 0.04–0.14 mg/L outside and 0–0.16 mg/L inside; and oxygen consumption was 1.68–2.47 mg/L outside and 2.00-2.84 mg/L inside the cages.

Feed Testing

Four types of diets based on soybean-cake meal and cotton-seed-cake meal with different protein levels were compared. Animal protein sources were silkworm chrysalis, fish meal, and bone meal. The nutrient composition of the feeds is listed in Table 3.

Feeding rates in 1986 and 1987 ranged from 3 to 5% of body weight. Fish were weighed at 15-day intervals, and the feeding rates were adjusted accordingly. Feeding frequency depended on the water temperature: the fish were fed five times per day at 20–25°C, and six times at temperatures above 25°C.

Results

Effects of Water Temperature on Stocking

When the difference in water temperature between the source of fingerlings and the cages was large, stocking mortality was high (Table 4). The survival rate (S) was linearly related to the temperature difference (Td):

[1] $S = 108.15 - 6.4395\ Td\ (r = 0.8478; p < 0.05)$.

When the water temperature in the cages is stable at 20°C and above, stocking of tilapia for cage culture can be carried out successfully (Table 4).

Relationship Between Stocking Size and Yield

Tilapia fingerlings with an average initial weight of 28.6 g grew to 382.1 g in 96 days, with an average daily gain of 3.86 g (Table 5). Fingerlings with an average initial weight of 82.0 g grew to 436.6 g, with an average daily gain of 3.69 g. Fingerlings with an average initial weight of 250 g had an average daily gain of

Table 1. Major limnological features in open waters (OW) and inside cages for experiments conducted in 1987.

	June		July		August		September	
Parameter	OW	Cage	OW	Cage	OW	Cage	OW	Cage
Temperature (°C)	22.5	22.8	25.9	26.1	27.8	27.9	24.9	24.9
Transparency (cm)	79	77	99	83	76	68	117	98
pH	7.15	7.0	7.0	7.0	7.2	6.82	—	—
DO (mg/L)[a]	9.7	9.6	5.84	5.73	4.6	3.38	5.28	5.18
COD (mg/L)[b]	1.68	2.00	1.96	2.40	—	—	2.47	2.84
NH_4^+-N (mg/L)	0.21	0.24	0.11	0.14	0.04	0.08	0.09	0.10
NO_3^--N (mg/L)	4.36	3.6	0	0	0.06	0	3.72	6.8
NO_2^--N (mg/L)	0.023	0.024	0.023	0.014	0.029	0.02	0.021	0.010
PO_4^--P (mg/L)	0.14	0.16	0.04	0	0.12	0.09	0.10	0.16
Hardness (me/L)	2.54	2.56	2.62	2.96	2.64	2.49	2.57	2.59
Alkalinity (me/L)	2.12	2.18	2.26	2.26	2.37	2.54	2.29	2.24
HCO_3^- (mg/L)	133.2	129.8	150.3	138.0	2.55	2.37	136.64	136.64
Cl^- (mg/L)	6.46	6.22	7.9	8.85	5.26	4.06	7.93	7.67
Phytoplankton								
(No. × 10^6/L)	12.38	9.87	6.81	4.26	11.81	9.84	11.48	17.06
(mg/L)	1.02	0.43	0.60	0.31	0.73	1.03	0.67	0.87
Zooplankton								
(No./L)	368	166	1 299	1 898	4 094	262	5 253	6 698
(mg/L)	0.50	0.43	0.61	0.74	0.63	0.37	1.16	0.72

[a] DO = dissolved oxygen.
[b] COD = chemical oxygen demand.

Table 2. Daily dynamics of dissolved oxygen (DO) and ammonium nitrogen (NH_4^+) outside and inside the cages.

Date and Time	DO (mg/L) Outside	DO (mg/L) Inside	NH_4^+ (mg/L) Outside	NH_4^+ (mg/L) Inside
17 August 1987				
1500	6.640	5.232	0.048	0.126
1800	6.103	5.018	0.091	0.189
2100	5.890	4.380	0.101	0.204
2400	5.720	4.020	0.124	0.245
18 August 1987				
0300	4.640	2.864	0.235	0.345
0600	4.657	3.396	0.198	0.265
0900	5.682	4.406	0.098	0.178
1200	6.243	5.183	0.056	0.143

Table 3. Proximate composition of test diets used in cage-culture experiments on tilapia.

Diet	Water (%)	Ash (%)	Lipid (%)	Protein (%)	NFE[a] (%)	Crude fibre (%)	Protein ratio[b]	FCR[c]	Cost (CNY/kg per fish)
1[d]	10.6	5.7	4.7	24.8	47.9	6.5	1:5.0	2.0	0.58
2	11.8	6.0	7.0	28.1	38.2	7.9	1:8.2	2.5	0.75
3	10.1	7.3	4.3	28.3	40.8	6.4	1:5.5	2.0	0.60
4	10.7	7.8	6.1	22.8	45.3	6.8	1:6.4	2.2	0.62

[a] Nitrogen-free extract.
[b] Ratio of animal to plant protein in diet.
[c] FCR = food converstion ratio.
[d] See Fig. 1 caption for description of diets.

Table 4. Differences in water temperature between the farm and the reservoir at the time of stocking, and the corresponding survival rate of fingerlings.

Farm (°C)	Reservoir (°C)	Survival (%)
28	18	30.2
	20	75.1
	23	89.6
25	18	50.4
	20	86.7
	23	95.0
23	18	64.2
	20	93.5
	23	98.9

Table 5. Rearing conditions of tilapia in different cage-culture experiments, 1986 and 1987.

	Cage		Stocking	Stocking density					Harvest		
	No.	Size (m^2)	size (g/fish)	kg/m^2	$No./m^2$	Days of rearing	Diet no.	Feeding rate[a]	weight (g/fish)	Yield (kg/m^2)	FCR[b]
1986											
	B2	4	75	35	467	104	2	5	293.4	111.5	3.1
	B3	4	100	35	350	104	2	5	328.6	103.8	2.7
	B4	4	45	35	778	104	2	5	320.7	161.8	2.3
1987											
	NF4	6.25	62.5	30	500	96	1	3.5–4.5	361.8	123.1	2.1
	NF5	6.25	28.6	14.3	500	96	1	3.4–4.5	382.1	162.2	1.3
	NF6	6.25	82	41.8	500	96	1	3.5–4.5	436.8	171.8	2
	SE4	9	250	160	64	96	1	3.5–4.5	842	44.6	2.4
	SE5	9	250	160	64	96	1	3.5–4.5	880	30.8	2.4
	SE6	9	250	160	64	96	1	3.5–4.5	850.3	41.2	2.4

[a] Feeding rate expressed as percentage of body weight per day.
[b] FCR = food conversion ratio.

6.25 g. As fingerling size increased, the average gain per day increased. Optimum stocking size is important for attaining yields and improved economic benefits.

Relationship Between Stocking Density and Yield

Optimum stocking density can result in a higher yield and higher individual gain (cages 1, 2, and 5 in 1987, Table 6). When the cage was stocked at a higher density (cage SF4 in 1987), individual harvest weight was not as high, although the overall yield was higher. Cage F4 in 1986, with the lowest density, gave the lowest overall yield.

Feed

Fish given diet 1 (soybean cake) grew better than those given diet 2 (cotton-seed cake) (Fig 1). The bean-cake diet or the cotton-seed-cake diet supplemented with some fish meal or silkworm chrysalis gave good results as well.

Yields from the three cages that had different feeding rate in 1986 did not differ significantly; however, the food conversion ratio (FCR) in cage E1 (low feeding rate) was lower than the FCR in the two cages with high feeding rates (Table 7). Therefore, the feeding rate was adjusted in 1987, when the diet ingredient giving the best growth was being used to decrease the FCR.

Table 8 indicates that the effect of minerals and vitamins on the growth of tilapia was significant. The yield from cages with additives was 21.5% higher than the yield from cages without additives.

Discussion and Conclusions

Dissolved Oxygen, Water Temperature, and Growth

The minimum DO level was always above 3 mg/L in cages with yields of 196 kg/m^2 in 1986. Zhang and Du (1984) reported that this was the minimum DO level required for common carp. Our results in 1986 show that DO differences (Table 2) were small inside and outside the cages when the fish biomass in the cages was less than 196 g/m^2. However, when the fish biomass was 242 g/m^2, DO and ammonium nitrogen showed significant differences inside and outside the cages. Swimming of the fish in the cages promoted water exchange, and, as a result, DO was continuously supplemented in the cages.

Water temperature differences influenced the survival rate of tilapia. Tilapia fingerlings in the study were generally brought from a pond warmed by a power plant or from warm springs where the water temperature was 22–30°C. In Jindou reservoir, water temperature reaches 20°C only in May, restricting the growing period in cages to 100–110 days. From our experiments and observations, two conclusions can be drawn: first, the water temperature should be 20°C or above at stocking; and, second, the smaller the temperature differences between the rearing pond and the cages, the higher is the survival rate. These are crucial factors in increasing the survival rate of tilapia fingerlings in northern China.

Table 6. Growth of tilapia in cages with different stocking densities, 1986 and 1987.

	Cage		Stocking	Stocking density					Harvest		
	No.	Size (m²)	size (g/fish)	kg/m²	No./m²	Days of rearing	Diet no.	Feeding rate[a]	weight (g/fish)	Yield (kg/m²)	FCR[b]
1986											
	F2	15	75	12	160	104	2	3.5–4.5	360.5	44	2.8
	F4	15	75	7.7	103	104	2	3.5–4.5	362.5	22.5	2.6
1987											
	SF1	6.25	31	13.6	438	96	1	3.5–4.5	351.6	83.4	1.8
	SF2	6.25	31	27.6	890	96	1	3.5–4.5	332.1	130.2	2.1
	SF3	6.25	31	57.2	1 838	96	1	3.5–4.5	199	238.9	2.2
	SF4	6.25	31	60.7	1 958	96	1	3.5–4.5	180	242.9	2.2
	SF5	6.25	31	33.5	1 080	96	1	3.5–4.5	320.7	199	2.2

[a] Feeding rate expressed as percentage of body weight per day.
[b] FCR = food conversion ratio.

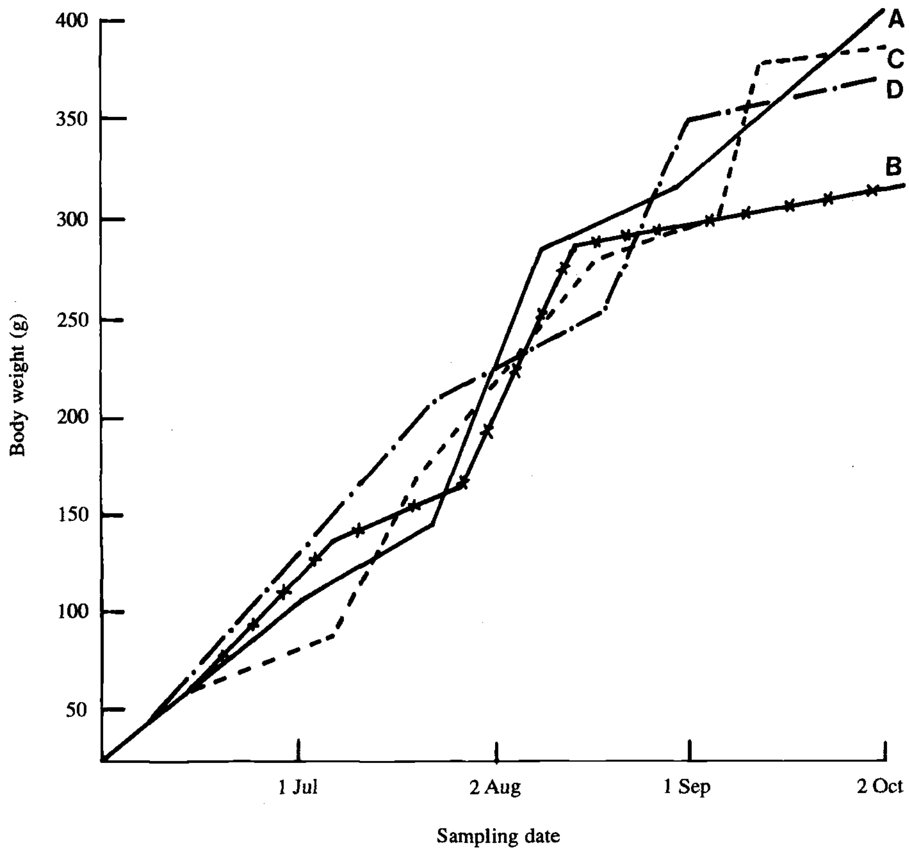

Fig. 1. Growth of tilapia fed different diets: A. diet 1 (soybean cake, 40%); B. diet 2 (cotton-seed cake, 40%); C. diet 3 (soybean cake, 30%, plus cotton-seed cake, 10%); and D. diet 4 (soybean cake, 20%, plus cotton-seed cake, 20%).

Stocking Size, Density, and Growth

Until a yield of 161.8 kg/m^2 was attained, individual growth rate did not decrease. As stocking density increased, individual growth rate and total yield decreased significantly. The suggested maximum stocking density is 2 000–2 500 fish/m^2, and the optimum stocking density is 300–600 fish/m^2 if the fingerlings are 30–50 g. Under these conditions, the final harvested weight can be more than 250 g.

Diet Ingredients

Cotton is widely planted in Shandong Province. Therefore, cotton-seed-cake meal was selected as a basic dietary material. Diets containing 40% cotton-seed-cake meal gave poor results (worse than a diet with 40% wheat bran). The performance of the tested diets is shown in Table 3. Diet 1 (soybean cake) was better than the others from the point of view of yield, food conversion ratio, and

Table 7. Growth of tilapia in cages with different feeding rates, 1986 and 1987.

	Cage		Stocking size	Stocking density		Days of rearing	Diet no.	Feeding rate[a]	Yield (kg/m^2)	FCR[b]
	No.	Size (m^2)	(g/fish)	kg/m^2	$No./m^2$					
1986										
	E1	8.75	45	7.8	174	104	2	3	42.2	1.7
	E5	8.75	45	7.8	174	104	2	5	41.6	2.2
	E6	8.75	45	7.8	174	104	2	8	41	2.7
1987										
	C1	8.75	34.7	15	432	96	1	2.5–3.5	80.7	1.6
	C2	8.75	34.7	15	432	96	1	2.5–3.5	81.3	1.6
	C3	8.75	34.7	15	432	96	1	2.5–4.5	75.9	2.3
	C4	8.75	34.7	15	432	96	1	2.5–4.5	65.9	2.3
	C5	8.75	34.7	15	432	96	1	2.5–5.5	90.7	2.1
	C6	8.75	34.7	15	432	96	1	2.5–5.5	88.6	2.1

[a] Feeding rate expressed as percentage of body weight per day.
[b] FCR = food conversion ratio.

Table 8. Growth of tilapia with and without vitamin supplements.

	Cage No.	Cage Size (m^2)	Stocking size (g/fish)	Stocking density kg/m^2	Stocking density No./m^2	Days of rearing	Diet[a]	Feeding rate[b]	Harvest weight (g/fish)	Yield (kg/m^2)	FCR[c]
1986											
	A2	15	45	7.5	166	71	Control	5	320.5	24.6	2.3
	A3	15	45	7.5	166	71	Test	5	338.2	29.9	1.9
1987											
	E1	9	48.5	15	309	96	Test	3.5–4.5	305	78.1	2
	E2	9	48.5	15	309	96	Test	3.5–4.5	315	85.7	2
	E3	9	48.5	15	309	96	Control	3.5–4.5	320	75.3	2.1
	E4	9	48.5	15	309	96	Control	3.5–4.5	330	72.0	2.1

[a] Control without vitamin supplements; test with vitamin supplements.
[b] Feeding rate expressed as percentage of body weight per day.
[c] FCR = food conversion ratio.

cost per kilogram of fish produced. Results from 2 years of experiments proved that cotton-seed cake is far inferior to soybean cake as a dietary ingredient.

Feeding Rates

No significant differences for different feeding rates were found in yield and weight gain, but the food conversion ratio was lower when the feeding rate was lower. With our diets, the best feeding rate for tilapia was 3–4.5% of body weight per day, but this must be adjusted according to water temperature, weather, and feeding conditions.

Zhang, L., Du, J. 1984. High yield fish culture in cages and its technological factors. Journal of Fisheries (China), 1, 19–32 (in Chinese with English abstract).

Comprehensive Techniques of Fish Culture in Shishantou Reservoir, China

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Comprehensive techniques of fish culture were adopted in Shishantou reservoir (17.3 ha) in 1985. Fish yield has increased from 86.2 kg/ha in 1984 to 7 822.5 kg/ha in 1989. These techniques have also been applied to 81 small reservoirs since 1984. The main features of this system are: stocking of mixed species, high stocking density, increased feeding, improvement of natural food production by fertilization, shortened fish-culture period by increased stocking size, self-sufficiency in fingerling production, harvest by net cage weirs, and integration of fish culture with poultry, livestock, and green feeds.

Since the 1950s, 1 078 large, medium, and small reservoirs have been created in hilly areas of Jiangsu Province. These reservoirs have brought advances in agricultural production and created favourable conditions for fish culture. Of the 1 032 small reservoirs (11 866 ha) in Jiangsu Province, only a small number were used in the 1960s and 1970s for extensive fish culture using natural food. This traditional culture method for Chinese reservoirs was limited by natural food and the main fishes stocked were silver carp and bighead carp. Fish output and economic profits were low and unstable.

Compared with large and medium reservoirs, small reservoirs have five main advantages that favour intensive fish culture: first, environmental conditions can be controlled; second, the fish are easy to feed and the reservoirs to fertilize; third, fish harvest is easy; fourth, dissolved oxygen (DO) concentration is higher and water quality is better than in fish ponds; and, fifth, they receive water rich in nutrients.

Experiments were conducted in Wagou reservoir (8.9 ha) in 1984, and in Shishantou reservoir and other reservoirs from 1985 to 1989. This paper presents details on the technological package that was developed.

Materials and Methods

Shishantou reservoir was impounded in 1957, has a catchment area of 5.6 km^2, and is located in Jiurong county, Jiangsu Province. Its average annual temperature is 15.2°C (with about 200 days suitable for growth) and it receives an average annual rainfall of 1 012 mm. The water area available for fish culture is 17.3 ha and the average water depth is 5 m. Wagou reservoir has ecological conditions that are similar to Shishantou, except that its area is smaller.

The experiment was conducted in three stages. Yield increased each year from 1 500 kg/ha in 1985 to 6 000–7 500 kg/ha in 1989.

Filter-feeding fish such as silver carp and bighead carp were the main species stocked in the first stage. The proportion of herbivorous and omnivorous fish stocked was increased to ensure better utilization of the natural food supply in the second and third stages. Management of water quality and feeding centred on ensuring an adequate food supply.

Fingerlings in the first stage were purchased. However, starting in 1986, fingerlings were cultivated in reservoir coves and ponds.

Nutrient concentrations and plankton biomass were measured monthly. Feeding and fertilization were carried out using organic fertilizers (swine and chicken manure and human wastes) and inorganic fertilizers (urea and calcium metaphosphate). The quantity of fertilizer was adjusted to maintain the plankton biomass at over 30 mg/L and the transparency at about 35–40 cm in the fertile zone. The main feed was rape-seed cake and the feeding rate was 2–5% of body weight. Pelleted diets with over 20% protein were used for cage culture. Water grass, rye grass, and other green feeds were also used.

Water quality was regulated with limestone at the rate of 150 kg/ha from July to September.

Results and Discussion

Fish Output and Weight Gain

Yearly stocking rates and yields from Shishantou reservoir indicate that, as stocking rate increased, fish yield per unit area increased (Table 1). The stocking ratio of silver carp and bighead carp was 66.4%, and the capture ratio was 61.5% in 1987. When the stocking ratio increased to 73.7%, the capture ratio remained at 62.2%. However, when the stocking ratio was dropped to 55.6%, the capture ratio decreased to 48.3% in 1989. In contrast, the capture ratio of grass carp, Chinese bream, common carp, crucian carp, tilapia, and other species that occupy the

Table 1. Stocking rates and yields from 1985 to 1989 in Shishantou reservoir.

	Stocking rate			Yield		
	Total	Filter feeders		Total	Filter feeders	
Year	(kg/ha)	kg/ha	%	(kg/ha)	kg/ha	%
1985	486.9	398.3	81.8	1 521.0	1 248.3	82.1
1986	827.3	526.5	63.6	3 328.4	2 107.4	63.3
1987	1 170.2	777.0	66.4	4 797.3	2 949.3	61.5
1988	1 206.0	888.9	73.7	5 791.5	3 603.0	62.2
1989	1 612.8	897.0	55.6	7 822.5	3 778.5	48.3

Table 2. Weight gain of different species in the year stocked.

Species	Stocking size (g)	Harvest size (g)	Weight gain	Final product
Silver carp	100–150	650–800	5–6 times	Market size
Bighead carp	100–150	600–750	4–6 times	Market size
Chinese bream	100	400–500	4–5 times	Market size
Chinese bream	10–25	100–200	8–10 times	Fingerlings
Common carp	50–100	800–1 000	6–10 times	Market size
Grass carp	150–250	1 200–2 000	5–8 times	Market size
Crucian carp	20–30	200–300	8–10 times	Market size
Crucian carp	15–20	210–240	10–14 times	Market size
Tilapia	2.5	50–70	20–30 times	Small size, low price
Tilapia	15–25	150–200	7–8 times	Market size

middle and lower parts of the water column increased as the stocking ratio increased, which indicated a higher stocking potency. The output of silver carp and bighead carp exceeded 50% in all years except 1989. The yields of bighead and silver carp probably did not reach 4 500 kg/ha in 1989 because the water-exchange rate was high.

When the total stocking rate was 7.70×10^4 kg, the yield was 31.01×10^4 kg with a population weight gain of 4.4 times in 5 years. The weight gain increased by only 3.1, 4.0, and 4.1 times in the 1st, 2nd, and 3rd years, respectively, but by 4.8 and 4.85 times in the last 2 years. There are three possible reasons for these observations:

- Small fingerlings were stocked in the 1st year;
- It was not possible to drain the reservoir and, as stocking rate increased and fishing techniques improved, the recapture rate increased; and
- Natural benthic food production improved with fertilization.

Changes in stocking rate on the basis of a revised plan and adjustments to the composition of the fish population by fishing improved fish growth. Weight gains are showed in Table 2.

Enhancing Plankton Biomass by Fertilization

Before fertilization, plankton biomass was 1.5 mg/L, which was lower than the level (7–10 mg/L) needed for normal growth of silver carp and bighead carp. In 1985 and 1986, plankton biomass increased with fertilizer input. For example, 6 375 t/ha of organic fertilizer were applied from March to May 1985 and plankton biomass rose to 6.5 mg/L at the end of April and to 13.12 mg/L in May. The plankton biomass dropped to 8.22 mg/L because of 122 mm of rain in June, but rose to 20.51 mg/L again in July with the application of 39.2 kg/ha urea and 20.6 kg/ha calcium metaphosphate from late June to July in spite of 136 mm of rain. The fish-yield target in 1986 was higher than the 1985 target when experience had shown that fertilizer added earlier in the year resulted in a wide fluctuation in plankton biomass that was not considered suitable for fish growth. Therefore, 5.8 t/ha of organic fertilizer was added to the reservoir between March and May

Table 3. Fertilizing rates in Shishantou reservoir in 1985 and 1986.

	1985				1986			
Month	Rainfall (mm)	Organic fertilizer (t)	Urea (kg)	Meta-phosphate (kg)	Rainfall (mm)	Organic fertilizer (t)	Urea (kg)	Meta-phosphate (kg)
Mar	87.9	3.00	—	—	44.9	2.10	—	—
Apr	49.2	2.48	—	—	64.9	1.82	—	—
May	139.0	0.90	—	—	33.6	1.80	—	—
June	122.4	0.64	15.0	7.5	180.3	1.73	—	—
July	135.8	1.76	24.2	13.1	170.6	1.05	78.4	41.3
Aug	97.6	0.68	—	—	92.8	0.71	75.0	75.0
Sept	114.6	0.64	—	—	46.0	0.75	37.5	—
Oct	195.8	0.19	—	—	31.6	0.45	—	—
Total	—	10.29	39.2	20.6	—	10.41	190.9	116.3

1986. As a result, the plankton biomass rose to 6.22–9.9 mg/L. Rates of fertilization are given in Table 3, and the changes in plankton biomass in relation to fertilizer applications are shown in Figs 1 and 2.

High plankton biomass was closely related to low rainfall between August and October, as well as high fertilization rates from July to September. Therefore, water quality and hydrology must be considered when fertilization rates are chosen.

A new method of fertilization was adopted in 1987 and 1988, based on a few easily determinable water-quality criteria, such as Secchi disk depth. Initial fertilization was conducted with 6–8 t of organic fertilizer in March. The fertilizer

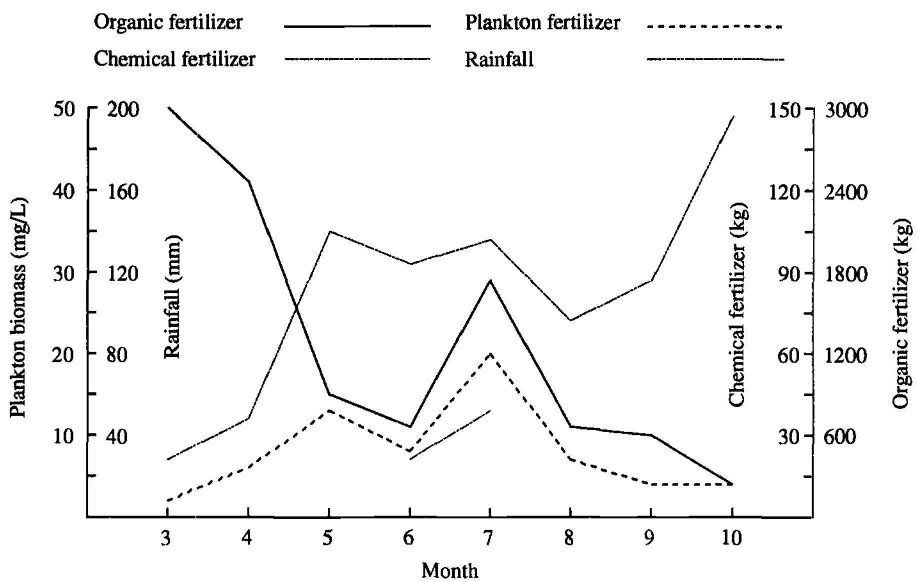

Fig. 1. Relationships among fertilizer rates, rainfall, and plankton biomass in 1985.

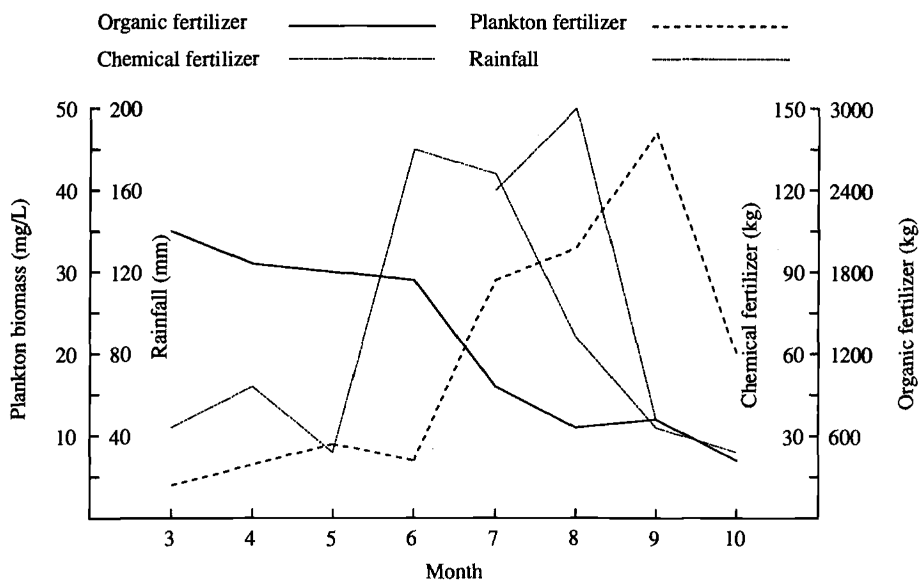

Fig. 2. Relationships among fertilizer rates, rainfall, and plankton biomass in 1986.

was added to the shallows and near the bank. After fertilization, plankton biomass rose rapidly to about 10 mg/L. During the growing season, from May to July, 5–7 t/ha of organic fertilizer were used on clear days. Plankton biomass remained over 30 mg/L and transparency was about 30–40 cm. Chemical fertilizers were added 9–12 times during the year at a rate of 30–45 kg/ha of urea and calcium metaphosphate (ratio 1:1).

Supplementary Feeding

Adequate DO is important for fish growth. When water temperature was 25–32.5°C, the DO concentration was 4.8–11.5 mg/L at 0.5–2.6 m depth, and 2.8–4.0 mg/L beyond 3 m. The stocking rate of fish that occupy the middle and lower areas of the water column was increased gradually in the second stage. This resulted in a higher ratio of these fish in the harvest than the ratio that was stocked. In 1987, for example, the stocking ratio accounted for 33.6% of the total stocking rate, but the harvesting ratio was 38.5%; in 1988, the harvesting ratio was 37.8% and the stocking ratio was 26.3%.

When the ratio of fish inhabiting the middle and lower parts of the water column was increased to 44.4%, the harvesting ratio increased to 51.7%. Common carp and crucian carp had the highest weight because there was adequate natural food supply and oxygen for growth. When we calculated total feeding rate, the feeding rate for middle and lower layer fish was 3.5 times the "food coefficient" of the expected fish yield, and for silver carp and bighead carp the feeding rate was 1.5 time the "food coefficient" of the estimated yield. Artificial feed such as rape-seed cake sank rapidly. Silver carp and bighead carp had a lower utilization ratio of this feed, and lower-layer fish had better access to the feed. The DO concentration was 0.5–0.9 mg/L when waste feed existed. This waste feed would decompose and act as a fertilizer. Therefore, the feeding rate should be adjusted to avoid oxygen depletion and partial pollution produced by overfeeding.

Shortening of the Culture Period

The fish-culture period can be shortened by 2–3 years by stocking 1- to 2-year-old fingerlings in proper proportions. To harvest market-size fish, the stocking size was determined by estimating weight gain times under the ecological conditions of the reservoir. All fish attained a marketable size the same year they were stocked when stocking sizes were: 100–200 g for silver carp; 100 g for bighead carp; 50–100 g for common carp; and 150–250 g for grass carp. Common carp grew to 0.8–1.0 kg, with a 6–10 times increase in weight, and had the highest growth rate. The harvesting ratio for bream was 54.2% with an average body weight of 400–480 g when the stocking size was 100 g. Only 10% of bream that were harvested reached a marketable size of 200–250 g when small fingerlings were stocked. Grass carp stocked at 50–100 g reached harvestable size in a short time.

All stocked fingerlings need not be 2 years old. For example, a stocking size of 15–30 g was adequate for certain crucian carp and tilapia because the market size of these species is smaller. Generally, 50–70 g market size could be reached the same year. The price of 250-g tilapia is 5–6 CNY/kg, but 50–70 g tilapia sell for only 2–3 CNY/kg (4 CNY = 1 USD). The 250-g tilapia could be produced in the same year if 15–20 g fingerlings were stocked.

Adoption of Cage Culture

Cage culture of grass carp, bream, and tilapia was conducted in large reservoirs from 1985 to 1989. Even after fertilization, there was a great disparity in the plankton biomass in different locations in the same reservoir although the water was fertile and the transparency was low. In these years, tilapia always grew very well in the net cages. The output of grass carp and Chinese bream in the cages was 7–10 kg/m^2 in 1985 and 1986. Growth of grass carp and Chinese bream was lower in 1987 than in 1985 despite higher feeding rates. Harvest size was about 1 kg, with a 2.5 times weight gain, when 2-year-old grass carp fingerlings (0.4 kg) were stocked. In addition, the fish were often diseased.

The output of grass carp and Chinese bream in less fertile water was 4 921.2 kg which accounted for 7.7% of total output from the reservoir in 1987. When the cages for tilapia were moved to a fertile area near a swine house, tilapia output increased each year. Tilapia output was 7 648.4 kg (30.35 kg/m^2 of cage) or 12% of the total fish yield from the reservoir. The output per unit area rose to 65.8 kg/m^2 of cage in 1988. The total output of grass carp, Chinese bream, and tilapia in net cage culture in 1987 was 12 570 kg, or 19.7% of total yield of cultured fish from the reservoir. It is thus clear that "intercropping" of cage culture in small reservoirs has a great future.

Fingerling Nursing in Coves

To shorten the culture period, it is desirable to stock large fingerlings. Generally, fingerling costs account for 35–40% of the total cost of intensive fish culture in reservoirs. The plan to increase fish yield per unit area from 1986 to 1989 meant that the cost of fingerlings would increase proportionately. To solve this problem, a shallow cove (4 ha) was partitioned with a net. From 1986 to 1988, fingerling output increased in the cove. In 1986, for example, 14 013 fingerlings were cultivated (4 125 kg of fingerlings per hectare). This output met the stocking requirement for 1 560 kg of fingerlings to obtain a yield of 4 500 kg/ha in 1987, and reduced fingerling cost by 20%.

Rearing Poultry and Livestock

In a sense, increasing the fish yield was a process of solving fertilizer- and feed-source problems. Adequate fertilizer must be provided if the main stocked species are silver carp and bighead carp. Two thousand geese were raised near the bank of the reservoir in the 1st year, and a 10-room swine house was built in the 2nd year to house over 100 pigs. In this way, over 100 t of organic fertilizer, which accounted for over 60% of the total needs for the reservoir, were provided. At the same time, 1.5 ha of mountainous region were planted in high quality green fodder that provided more than 100 000 kg of feed per year for the grass carp and Chinese bream.

Escape Prevention and Capture of Demersal Fish

Because of the varied bottom topography, it is difficult to catch demersal fish. This is the main reason why the stocking rate and output of middle- and lower-layer fish were low. Net cage weirs (300 m long) were installed at the main intake of Shishantou reservoir from 1986 to 1989. The weirs prevented escape, and the net trapped the demersal fish. From April to September, 8 750 kg of fish (38.3% of the total fish yield) were caught in the weirs. Later, weirs were installed in areas where feeding and fertilizing are not done. This makes it easier to catch demersal fish.

Cost–Benefit Analysis

From 1985 to 1989, Shishantou reservoir yielded 310.1 t of marketable fish. Income increased to 1.20 million CNY, and the profit was 0.4 million CNY (Table 4). These profits have been used to build 34 houses, and improve the drainage

Table 4. The economics of fisheries activities in Shishantou reservoir from 1985 to 1989.[a]

		Economic profit				
Year	Output (t)	Income (CNY)	Profit (CNY)	Profit (CNY/ha)	Profit (CNY/kg)	Cost (CNY/kg)
1985	20.3	83 880	23 430	1 758	0.58	1.94
1986	44.4	162 910	40 980	3 073.5	0.52	2.02
1987	63.9	265 360	84 980	6 373.5	0.96	2.28
1988	77.2	342 580	116 860	8 764.5	1.10	2.28
1989	104.3	343 660	135 280	10 146	1.21	2.26
Total	310.1	1 198 390	401 530	—	—	—

[a] Total fish output was 1.5 t (86.25 kg/ha) and no profit was realized in 1984.

system for 2.1 ha of fingerling ponds. The income of 24 employees increased to 2 100 CNY/year. This income is over twice that of the rural workers and was higher than that of factory workers.

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Economics of Carp Cage Culture, Pokhara Valley, Nepal

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This study determined the profitability of the carp cage culture practiced by 188 operators in three lakes in Pokhara Valley: Begnas, Phewa, and Rupa. Stratified sampling, representing 50% of the population, was adopted using a pretested interview schedule. Background information, basic sociodemographic characteristics of operators, information on cage culture management practices, cost and return analysis, and problems faced by cage operators are presented.

*On average, the cage volume used by each operator was 94.12 m^3; total capital investment was 73.75 NPR/m^3; total average annual production was 2.03 kg/m^3; and net benefit was 31.22 NPR/m^3 (1 USD = 18 NPR). All operators sold fresh fish at 26.95 NPR/kg. Silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) were the main species used in cage culture. The major problems identified by cage operators in the three lakes were: shortage of fry or fingerlings; limited market; high price of inputs; and lack of skilled labour.*

Cage culture is a new aquaculture development and investment in Nepal. In 1971, fish cages were introduced as holding structures for brood fish in Phewa Lake, Pokhara Valley (Rajbanshi and Sharma 1980). In 1975, an integrated fishery and fish-culture development project was started through cooperation of the Government of Nepal, the United Nations Development Programme (UNDP), and the Food and Agriculture Organization (FAO). Since 1976/77, experiments on cage culture have been carried out in the lakes of Pokhara Valley.

Private sector interest and participation in cage-culture activities began in 1978, and cage culture is now being adopted enthusiastically by the private sector in the Pokhara Valley.

There are 300 landless fishermen living along the lake shores who were totally dependent on capture fisheries for their livelihood. Various efforts have been made to improve the fish catch from the lakes by introducing improved fishing gear and by stocking fish seed (fry or fingerlings). However, expected improvements were not realized, nor were income levels increased.

Of the 300 fishermen, 188 are engaged in cage culture. There were 326 cages (total volume 16 018.7 m^3) in 1987/88. Because of the economic gains, the number of fishermen adopting cage culture is increasing annually by about 10%. Fish culture spread to the Kulekhani hydroelectric reservoir in 1985.

This study aimed: first, to identify and describe the existing culture system, including labour utilization, source of fish stock, and use of production inputs; second, to determine the costs and returns of the cage culture of carps; third, to present a brief description of the marketing system and practices; fourth, to identify basic problems encountered by the fish farmers; and, fifth, to present the basic sociodemographic characteristics of the fish farmers.

Methodology

This study was conducted in lakes Begnas, Phewa, and Rupa in the Pokhara Valley, Nepal. A list of carp-cage operators was obtained from the Fisheries Development Centre, Pokhara, and was used as the sampling frame. Following a stratified sampling procedure, cage operators, representing about 50% of the population, were interviewed (Table 1). Data were obtained by personal interviews during 1989 using a pretested interview schedule, and production information was obtained for the fiscal year 1987/88.

Results and Discussion

Sociodemographic Characteristics of Fish Farmers

Cage culture operators in the Pokhara Valley are, on average, 36 years old and have six members in their household. The farmers have an average of 17.6 years of experience in capture fisheries, and have been engaged in fish culture for about 6.6 years. All respondents were part-time fish farmers who obtained 26.2% of their

Table 1. Cage culture operations in Pokhara Valley, Nepal (1987–1988).[a]

	1st stratum		2nd stratum		Total	
Lakes	No. of operators	Volume (m^3)	No. of operators	Volume (m^3)	No. of operators	Volume (m^3)
Existing operations						
Begnas	22	1 133.5	24	3 195.2	46	4 328.7
Phewa	32	1 752.0	6	1 046.0	38	2 798.0
Rupa	62	3 245.0	42	5 647.0	104	8 892.0
Total	116	6 130.5	72	9 888.2	188	16 018.7
Present study						
Begnas	11	650.0	13	2 082.0	24	2 732.0
Phewa	16	796.0	3	400.0	19	1 196.0
Rupa	31	1 936.0	21	2 148.5	52	4 084.5
Total	58	3 382.0	37	4 630.5	95	8 012.5

[a] Information on existing operations obtained from Fisheries Development Centre, Pokhara. First stratum represents operators with less than 100 m^3 in cages: second stratum represents operators with 100 m^3 or more in cages.

Table 2. Demographic characteristics of cage operators.

	Begnas	Phewa	Rupa	Average
Age (years)	38.30	38.53	34.63	36.32
Household size (no.)	5.69	4.34	5.60	6.10
Years of experience in				
Capture fisheries	22.18	20.31	11.94	17.55
Cage culture	6.69	8.79	5.77	6.61
Percentage income from cage fish culture	24.30	27.89	28.13	26.15
System of culture (no. of operators)				
Monoculture	5	11	39	55
Polyculture	19	8	13	40

income from cage culture, and the remainder from capture fisheries, cereal-crop farming, and other jobs. Monoculture was practiced by 58% of the fishermen; 42% practiced polyculture (Table 2).

Most of the fishermen (48%) had no formal education; 23% had no schooling but could read and write; 16% had an elementary education; and 13% had a high-school education. Know-how in cage culture was obtained through word-of-mouth (45%) and through training (55%). The training was obtained from the Fisheries Development Centre, Pokhara.

Information on Cages

Fish farmers operated an average of 94.12 m^3 of cages, and all farmers except one owned their cages. The average nursery cage was 23.22 m^3; the average production cage was 49.16 m^3. There were two types of cages (netlon and nylon), and the average cage age was 6.5 years (Table 3).

Management Practices

Monoculture and polyculture production systems were practiced. The three lakes are rich in natural food. The planktivorous fish species, silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*), were the most popular species cultured. Only a few farmers raised Indian major carp, such as rohu (*Labeo rohita*) and catla (*Catla catla*). All fish species were raised on the natural food in the lakes; no supplementary feed was given.

The average stocking rate of carps in the production ponds was 8 fish/m^3 for monoculture and 9 fish/m^3 for polyculture; 21.9-g fish were used for monoculture; 29-g fish for polyculture. All farmers had one crop in 12 months. The average stocking ratio of silver carp, bighead carp, and Indian major carps in polyculture was about 43%, 56%, and 1%, respectively. The average stocking rate in nursery cages was 36 fingerlings/m^3 for monoculture and 71 fingerlings/m^3 for polyculture; the stocking size was 6.1-g fingerlings for monoculture and 4.1-g fingerlings for polyculture. The average nursing time was 74 days for monoculture and 84 days for polyculture (Table 4).

Table 3. Information on cages.

	Begnas	Phewa	Rupa	Average
Average volume of cages (m^3/operator)	125.55	81.32	84.29	94.12
Average volume of leased cages (m^3/operator)	—	—	100.0	100.0[a]
Average size of cage (m^3)				
Nursery	8.73	31.73	18.66	23.22
Production	48.79	47.84	49.81	49.16
Average depth of cage (m)	2.00	2.18	1.99	2.02
Average age of cage (years)	6.42	8.71	5.77	6.54
No. of operators[b]				
Kinds of cages				
Netlon	10	14	15	39
Nylon	24	14	52	90
Types of cages				
Nursery	14	11	16	41
Rearing/production	24	19	52	95

[a] Only one operator leased cages; he had his own cages as well.
[b] More than one kind or type of cage was owned by the operators.

Total annual production of carps was 2.48 kg/m^3 for monoculture, and 1.68 kg/m^3 for polyculture. The average for both culture systems was 2.03 kg/m^3. The production level in the first stratum was higher than the production level in the second stratum (Table 5).

Cage operators select the species to be cultured based on: availability of fry or fingerlings (31.87%), market demand (28.13%), and keeping quality (11.87%).

All farmers are dependent on the Fisheries Development Centre, Pokhara, for their fish seed. None of the farmers reported that their cages remained idle during the year. However, nursery cages were not used throughout the year. All farmers had one crop per year.

The unavailability of fingerlings when needed and financial difficulties were common problems. The price of fingerlings was determined by the prevailing price in government farms. The average price per fingerling was 0.50–1.04 NPR, depending on weight (18 Nepalese rupees (NPR) = 1 United States dollar (USD)).

Harvesting and Marketing Practices

Only 8.4% of the operators harvested their cages totally; most harvested their cages selectively. The only harvesting method is lifting the cages and scooping the market-size fish. The average size of fish at harvest was 597.4 g. The reasons given for harvesting smaller fish were: need for money (60%), availability of fingerlings (24.8%), maximize production (8.8%), and market strategy to get highest price (6.4%).

All the farmers surveyed sold fresh fish. About 41% of the farmers sorted or graded the fish by weight and size. None of the farmers packed their product before

Table 4. Annual stocking rates and culture practice.

	Begnas				Phewa				Rupa				Average			
	Monoculture		Polyculture		Monoculture		Polyculture		Monoculture		Polyculture		Monoculture		Polyculture	
	Nursery cage	Prod. cage	Nursery cage	Prod. cage	Nursery cage	Prod. cage	Nursery cage	Prod. cage	Nursery cage	Prod. cage	Nursery cage	Prod. cage	Nursery cage	Prod. cage	Nursery cage	Prod. cage
Average stocking rate ($fish/m^3$)	33.85	5.73	8.65	7.59	19.79	15.12	23.10[a]	6.08[a]	41.08	6.96	116.61[a]	10.46[a]	33.50	8.28	70.63	8.86
Silver carp	33.33	—	8.65	7.59	—	—	na	na	41.08	8.98	na	na	40.93	8.98	8.65	7.59
Bighead carp	36.00	5.73	8.65	7.59	19.79	15.12	na	na	—	6.00	na	na	30.24	7.76	—	—
Indian major carp	—	—	4.00	8.35	—	—	—	—	—	—	—	—	—	—	4.00	8.35
Average stocking size (g/fish)	6.00	21.75	4.10	18.67	4.27	29.50	4.27	45.00	6.75	19.13	4.00	27.96	6.06	21.87	4.08	29.02
Average number of croppings	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Average length of cropping (months)	3	12	5.14	11.76	3	12.00	2.00	12.00	2.00	12.00	2.00	12.35	2.45	12.00	2.79	12.13
Average stocking ratio in polyculture																
Silver carp	—	—	—	35.43	—	—	—	10.00	—	—	—	58.07	—	—	—	42.73
Bighead carp	—	—	—	64.57	—	—	—	85.50	—	—	—	41.93	—	—	—	56.36
Indian major carp	—	—	—	—	—	—	—	4.50	—	—	—	—	—	—	—	0.91

[a] Fingerlings stocked mixed with silver carp and bighead carp.

Table 5. Fish production (kg/m^3) by stratum and production system.[a]

Use and Stratum	Production system	Begnas	Phewa	Rupa	Average
Sold					
1st stratum	Mono	1.875	1.988	2.692	2.481
	Poly	1.444	1.507	1.780	1.591
2nd stratum	Mono	1.133	1.800	2.333	2.191
	Poly	1.203	1.900	2.514	1.607
Home consumption					
1st stratum	Mono	0.075	1.130	0.143	0.134
	Poly	0.049	0.044	0.127	0.077
2nd stratum	Mono	—	—	0.118	0.118
	Poly	0.030	0.050	0.170	0.068
Others					
1st stratum	Mono	0.050	—	0.011	0.013
	Poly	—	—	—	—
2nd stratum	Mono	—	—	0.016	0.016
	Poly	—	—	0.033	0.033
Total					
1st stratum	Mono	2.601	2.118	2.846	2.628
	Poly	1.493	1.551	1.907	1.668
2nd stratum	Mono	1.303	1.800	2.467	2.304
	Poly	1.233	1.907	2.717	1.683
Total					
Monoculture		1.629	2.047	2.656	2.479
Polyculture		1.283	1.711	2.378	1.678
Grand total		1.327	1.836	2.567	2.035

[a] The average price of fish was: 24.28 NPR/kg in Begnas; 37.21 NPR/kg in Phewa; 24.78 NPR/kg in Rupa. The overall average price was 26.95 NPR/kg.

it was sold. Only 20% of the cage operators sold their fish directly; 80% sold to agents and fish dealers. All fish were picked up at the lake.

All cage operators received cash payment. Fish prices were based on the agreement between buyer and owner (82.1%); dictated by the owner (8.4%); dictated by the buyer (6.3%); or based on the prevailing price (3.2%).

There were 85 operators who knew the final destination of their products. Of the outlets, 15% were within the village; the balance were outside the village, but within Pokhara.

Cage operators sold their fish to a regular buyer. Producers were identified as a potential source of fish by direct contact by the buyer (53.7%), advertisements on signs in the street (19%), advertisements in the media (17.9%), and referrals from former contacts (9.5%).

Labour Utilization

A total of 0.1619 days/m^3 per year were spent on cage production. The labour used for each operation is given in Table 6. Cleaning of cages required 29% of the time; cage preparation required 24% of the time. About 62% of the total labour was provided by the operator and family members; the rest was hired labour.

Capital Investment

Net material was the major capital investment (79.7%). Other costs were: cage making (12.7%), float materials (4%), cage frame (1.9%), and rope and anchors (1.8%). Average total capital investment was 73.75 NPR/m^3 (Table 7).

Annual Expenses

Two types of expenses for carp production are presented in Table 8. Cash expenses are those that required actual monetary outlays. Total cash expenses were 14.31 NPR/m^3 (60.5% of the total expenses). The major cash costs were: miscellaneous expenses (22.9%), fry or fingerlings (22.4%), and labour (7.9%).

Noncash expenses included unpaid operators and family labours, and depreciation. Total noncash expenses were 9.33 NPR/m^3 (39.5% of total costs).

Table 6. Annual labour utilization (person-hours/m^3)[a] by type of operations.

				Average	
	Begnas	Phewa	Rupa	Person-hours/m^3	%
Cage preparation	0.28	0.52	0.40	0.40	24.46
Stocking	0.10	0.16	0.13	0.13	7.97
Defouling	0.26	0.54	0.54	0.47	28.78
Repair and maintenance	0.19	0.32	0.27	0.26	15.94
Harvesting	0.11	0.23	0.16	0.16	10.13
Sorting/marketing	0.08	0.23	0.26	0.21	12.72
Total	1.02	1.99	1.76	0.62	100

[a] 1 person-day assumed to be 10 person-hours.

Table 7. Capital investment (NPR/m^3).[a]

				Average	
	Begnas	Phewa	Rupa	NPR/m^3	%
Net material	58.708	53.389	60.832	58.807	79.73
Float material	1.952	8.050	1.529	2.940	3.99
Cage construction	3.253	17.999	9.013	9.355	12.68
Rope and anchors	1.335	2.339	0.883	1.288	1.75
Cage frame	1.263	2.836	0.872	1.364	1.85
Total	66.511	84.613	73.129	73.754	100

[a] 18 Nepalese rupees (NPR) = 1 United States dollar (USD).

Table 8. Annual expenses (NPR/m^3) for cage culture.[a]

	Begnas	Phewa	Rupa	Average NPR/m^3	Average %
Cash expenses					
Fingerlings	5.201	5.240	5.340	5.286	22.36
Labour	2.110	2.560	1.520	1.877	7.94
Interest on loan	0.916	1.950	1.330	1.349	5.71
Marketing costs	0.202	0.770	0.310	0.376	1.59
Other expenses	6.036	7.620	4.330	5.419	22.92
Subtotal	14.465	18.140	12.830	14.305	60.52
Noncash expenses					
Unpaid operator/ family labour	1.673	3.940	3.440	3.094	13.10
Depreciation	7.500	7.210	5.300	6.238	26.38
Subtotal	9.173	11.150	8.740	9.332	39.48
Total	26.638	29.29	21.57	23.637	100.00

[a] 18 Nepalese rupees (NPR) = 1 United States dollar (USD).

Annual Receipts

Cash was obtained from the sale of carp and comprised 95% of the total returns. Noncash receipts (a total of 5%) included the value of fish eaten at home, and those that were given away (Table 9). The value of the carp used at home is small; however, it does emphasize the importance of carp production as a source of food for the cage operators and their families.

Costs and Returns

The costs and returns of carp production are itemized in Table 10. On average, net cash income amounted to 37.80 NPR/m^3 per year, and there was a loss of 6.6 NPR/m^3 per year in noncash income because of the very small amount of fish consumed at home in comparison with the operator and family labour used in production. The net earnings of 31.20 NPR/m^3 per year show the profitability of carp culture.

Problems Faced by Cage Operators

Carp producers encountered several problems in their operations. A shortage of fingerlings was the major problem reported by 66.3% of the operators. Other problems were limited market, high price of inputs, lack of skilled labour, limited management expertise, climatic problems, poaching, lack of support and infrastructure, unavailability of credit, and lack of extension services.

Table 9. Annual receipts (NPR/m^3) from cage cultures.[a]

	Begnas	Phewa	Rupa	Average NPR/m^3	Average %
Cash receipts					
Sale of carp	31.29	65.87	62.00	52.12	95.01
Noncash receipts					
Value of carp used at home	0.85	2.45	3.67	2.53	4.61
Others[b]	0.09	—	0.37	0.21	0.38
Subtotal	0.94	2.45	3.94	2.74	4.99
Total	32.23	68.32	65.94	54.87	100.00

[a] 18 Nepalese rupees (NPR) = 1 United States dollar (USD).
[b] Includes mortality and gifts.

Table 10. Cost and returns (NPR/m^3 per year) from cage culture.[a]

	Begnas	Phewa	Rupa	Average NPR/m^3 per year	Average %
Return					
Cash	31.29	65.87	62.00	52.12	95.01
Noncash	0.94	2.45	3.94	2.74	4.99
Total	32.23	68.32	65.94	54.86	100.00
Costs					
Cash	14.47	18.14	12.83	14.31	60.53
Noncash	9.17	11.15	8.74	9.33	39.47
Total	23.64	29.29	21.57	23.64	100.00
Net cash income	16.82	47.73	49.17	37.81	121.11
Net noncash income	−8.23	−8.70	−4.80	−6.59	−21.11
Net earning	8.59	39.03	44.37	31.22	100.00

[a] 18 Nepalese rupees (NPR) = 1 United States dollar (USD).

Summary and Recommendations

This study indicates that cage culture of carps is economically feasible and has the potential for further development. Earlier studies also suggested that the cage culture of carps in the Pokhara Valley was economically viable (Pradhan 1979; Sharma 1979; Pillai and Sollows 1980). However, fish production reported earlier was 7–9 kg/m^3 (Pradhan 1979; Sharma 1979; Pillai and Sollows 1980; Swar et al. 1982), which is much higher than the 2.03 kg/m^3 reported in this study. The difference in reported productivity may be due to sample size, sampling procedure, the cultured species and their combinations, and management practices.

Productivity varied widely among producers having similar systems of production. Therefore, the production (and profit) of cage operators who achieved less than the average production rate could be increased by using higher levels of inputs, and by providing greater attention to management.

Cage operators have a choice of only two fish species (silver carp and bighead carp). Therefore, the suitability of introducing other planktivorous species for cage culture should be evaluated. Supplementary feeding of fish and its economics should also be studied.

The existing marketing system should also be improved (Sharma and Swar 1987). The farmers claim to be unable to intensify their production systems because of the problems and constraints they encounter. Although credit schemes exist for cage operations, the farmers apparently do not use them. There is also an urgent need to upgrade the technical know-how of fish farmers. The government of Nepal could, therefore, assist the industry by extending more technical support. The present per capita fish production of about 1 290 g in 1987/88 (FDD 1988) could be increased through intensification of existing cage culture, through expansion of cage culture into the 5 000 ha of lakes and 1 380 ha of reservoirs available in the country (ADB and HMG/N 1982; APROSC 1986).

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Integrated Fish Farming in Small Reservoirs, China

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An average fish yield of 4 774–10 199 kg/ha was achieved by: comprehensive development and utilization of water and land resources; establishment of crop-production areas; adjustment of the integration ratio of fish, livestock, poultry, and grass; and improvement of the traditional farming system. To produce 1 kg of fish from these oligotrophic reservoirs, 0.242 kg of fingerlings, 1.58 kg of commercial feed, 8.28 kg of green fodder, 1.88 kg of animal manure, and 0.27 kg of quicklime were needed. Further development and utilization of the resources and the deposit of silt improved autochthonous nutrition and, as a result, reservoir productivity, the survival rate of stocked fish, and the food conversion rate were increased.

All fish-farming systems that have high productivity have resulted mainly from intensive culture and high inputs of energy. The traditional system had silver carp (*Hypophthalmichthys molitrix*) and bighead carp (*Aristichthys nobilis*) as the primary species. This farming system was limited largely by the abundance of natural food organisms. Production in oligotrophic reservoirs can be increased by increasing the energy input, developing and protecting the land area of the catchment, cultivating good pasture grasses, and farming animals around reservoirs. These practices provide both food and manure.

Since 1984, integrated fish farming has been studied in several small reservoirs with a storage capacity of $<6 \times 10^3$ m^3, and an area of <30 ha. The major objectives of this study were:

- To establish an artificial, complex ecosystem, through development and utilization of both the water and land resources of the reservoirs — setting up pasture production bases; adjusting the integration ratio among fish, livestock, poultry, grass, and pearl culture; and improving the farming system; and
- To develop a vertically integrated predictive model for reservoir fisheries (Fig. 1).

Since 1986, an average fish yield of 6.529–10.199 t/ha has been obtained every year from the five experimental reservoirs. In 1989, a yield of 14.45 t/ha was achieved in Wuxi reservoir (2.8 ha).

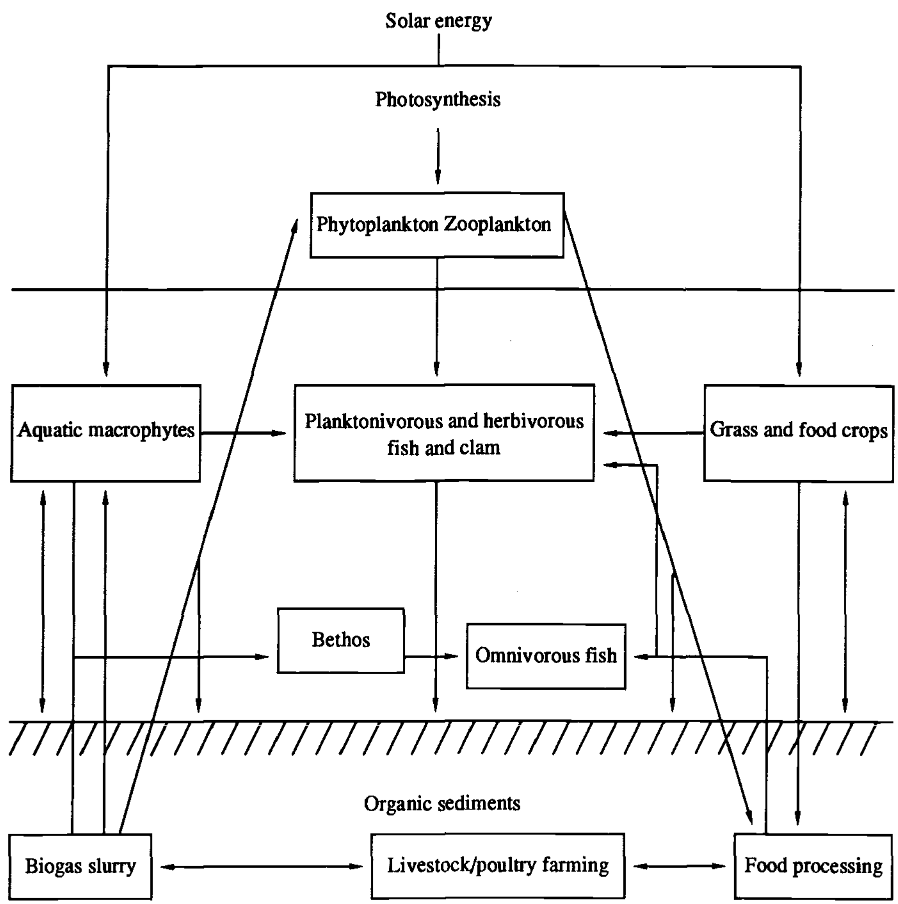

Fig. 1. Ecologically oriented fisheries production in experimental reservoirs.

Materials and Methods

Natural Conditions

The five experimental reservoirs (Table 1) are located in Daixi District, 20–25 km from Huzhou, in Zhejiang Province (119°50′–120°00′E; 30°37′–30°47′N). This district lies in the southern part of the subtropical zone and has abundant water resources and illumination, and favourable temperature. The average annual air temperature is 14.9–15.8°C (maximum 39°C; minimum −11°C); average annual sunshine is 2 124.5 h; irradiation is 456 kJ/cm^2; average annual rainfall is 1 327–1 350 mm; and the total temperature accumulation (above 10°C) is 4 725 C°. The minimum and maximum water temperatures at the surface are 4.5°C and 30.9°C, respectively, and the average temperature is 17.7–18.6°C. Water pH is 5.4–6.3. Therefore, all ecological conditions are favourable for rearing silver carp, bighead carp, grass carp (*Ctenopharyngodon idellus*), bream (*Megalobrama amblycephala*), common carp (*Cyprinus carpis*), crucian carp (*Carassius auratus*), and *Distoechodon tumirostris*. Moreover, there were no other fishes living in the upper reaches of the reservoirs. Before the experiment started, water transparency was 1.5–2 m, and the average annual fish yield was 62.89–180.94 kg/ha in these typical oligotrophic reservoirs (Table 1) (Chen 1982).

Technical Strategies

A special integrated fish-farming system was developed. Water and soil conservation was a prerequisite of the system. Pasture production was used for fish food, fish and pearl culture were improved, animal farming was used to transform energy, and bamboo, fruits, melons, tea, timber, and other byproducts were produced to increase the economic efficiency of the system. In addition, a technical package was developed to reduce diseases and limit predators; to increase stocking size; to replace silver carp and bighead carp with grass carp, bream, common carp, and crucian carp as the primary species and a change from an extensive to an intensive culture system; to integrate fish farming with grass, animal, and pearl production; and to change slightly acid water into neutral or slightly alkaline water. Fingerling and clam nursery ponds were also completed (Lu 1987).

Stocking of Fingerlings

In 1983, in the five experimental reservoirs (total culturable area 11.33 ha), the average stocking number was 552 fish/ha, the average stocking weight was 8 kg/ha,

Table 1. Basic information on the experimental reservoirs.

Reservoir	Catchment area (km^2)	Dam height (m)	Irrigation area (ha)	Storage capacity (10^4 m^3)	Culturable area (ha)	Water depth (m)
Fengchekou	1.69	13	30	27	2.66	4.0
Guanmenchong	0.80	9.8	20	15	1.87	3.9
Xiyangshan	0.50	10	26.67	12	1.0	4.0
Dashanwu	1.60	13	37.33	30	3.0	5.0
Wuxi	0.68	9.6	80	40	2.8	3.5
Average	1.05	11.08	38.8	24.8	2.27	4.08

Table 2. Annual stocking rates and yields in the experimental reservoirs (integrated fish farming was initiated in 1985).

Year	Stocking		Harvest	
	kg/ha	fish/ha	kg/ha	fish/ha
1983	8	552	63	—[a]
1984	15	971	181	—[a]
1985	507	15 907	4 774	9 614
1986	1 526	13 955	6 529	10 600
1987	1 289	11 108	6 011	9 547
1988	1 755	13 024	8 121	22 526
1989	2 193	27 046	10 199	42 315

[a] Unknown.

and the average stocking size was 15.02 g/fish. This was increased in 1989 to 27 046 fish/ha, 2 193 kg/ha, and 81.08 g/fish (Table 2).

The stocking ratio of silver carp and bighead carp was decreased from 95% in 1983 to 26.67% in 1989. The stocking ratio of grass carp, bream, common carp, and crucian carp was increased from 5% in 1983 and 1984 to 73.33% in 1989.

Prevention of Fish Diseases

As stocking density and feeding intensity increased, the prevention of fish diseases became important. The measures practiced in the experiment included: reservoir treatment with quicklime; fingerling disinfection; regular application of chemicals; implementation of the four feeding principles (fixed feeding time, place, quantity, and quality); fermentation of animal manure; and self-supply of fingerlings. At the end of each production season, reservoirs were treated with quicklime at a rate of 750–1 125 kg/ha. During April to September, quicklime solution was applied at a dosage of 150 kg/ha. In addition, baskets containing either bleaching powder or fish medicine no. 1 were hung around the fish-feeding platforms when outbreaks of fish diseases occurred.

Before stocking, fingerlings were normally treated in a solution of dipterex (90% crystal) or bleaching powder (30% chlorine) for 5–10 minutes at a concentration of 2–4%. To further increase the survival rate of stocked fish, animal manure was fermented before application or put into biogas digestors to eradicate pathogenic bacteria and parasites.

Rearing Management

To provide all the stocked fish with food organisms, the base manure was usually applied at a rate of 11.25–15 t/ha before the fingerlings were stocked. In general, feeding started as early as March, when the surface water temperature was above 10°C; feeding gradually stopped about 20 November, when the surface water temperature dropped below 10°C. Feeding and manuring details are given in Tables 3 and 4.

Integrated Establishments

To reduce the production cost, increase the input, and to ensure the availability of food and manure for fish production in the reservoirs, a fish food-processing

Table 3. Feeding and manuring strategies[a] adopted (per hectare of water area) in the experimental reservoirs.

Year	CF (kg)	GF (kg)	SM (kg)	PF (kg)	RSC (kg)	QL (kg)
1985	6 915	36 010	34 608	66	17 359	1 104
1986	8 028	38 443	45 245	749	21 365	1 061
1987	9 339	34 290	26 909	666	19 884	265
1988	14 484	31 817	56 829	537	27 335	702
1989	11 667	31 402	107 442	653	29 671	684

[a] CF = commercial food; GF = green fodders; SM = stable manure; PF = phosphate fertilizer; RSC = rapeseed cake; QL = quicklime.

Table 4. Percentage of monthly feeding and manuring in the experimental reservoirs.

Month	Green fodder	Commercial food	Phosphate fertilizer	Stable manure
March	0.5	0.7	—	25
April	3.0	2.3	—	10
May	10	4	5	15
June	14	6.5	40	20
July	19	12.5	25	—
August	20	16.5	20	—
September	17.5	22.5	10	—
October	11	19	—	20
November	5	13.5	—	10
December	—	2.5	—	—

factory was set up, with an annual production capacity of 5 000 t. To conserve both water and soil, 19 terraced ponds with a total water area of 1.76 ha were constructed for fingerling and pearl clam production. At the same time, four chicken farms, three duck farms, and four pig farms were built. On average, every hectare of reservoir used for fish production required 0.155 ha of fingerling ponds, 0.77 ha grassland, 2 912–3 177 chickens, 335–609 ducks, and 12–15 pigs. In addition, five tractors, one 1.5-t truck, and nine pumps were purchased. Around the reservoirs, 102 ha of fir forest, 34.6 ha of bamboo, 32.67 ha of orchard, 12 ha of tea, and 8.69 ha of pasture crops were developed. Another 220 ha of hillside were reserved for reforestation.

Results

Physicochemical Factors and Natural Food Organisms

To make a comprehensive study on the productivity of high-yield reservoirs and ponds, and to evaluate the efficiency of practicing integrated farming in small reservoirs, synchronous tests were performed in Fengchekou reservoir and in the intensively managed Tantangyong pond, Yongdon fish farm (2.33 ha). The results are given in Tables 5 and 6.

The concentration of nutrients increased with intensive feeding and manuring and regular application of quicklime. However, all the parameters in the reservoirs, except total alkalinity, Ca^{+2}, and total phosphorus, were the same or slightly higher than those in the high-yield ponds.

Fish Production

In 1989, the average gross fish yield was 10 199 kg/ha and the average net fish yield was 8 006 kg/ha, which was comparable to high-yield ponds in China. In Wuxi reservoir (2.8 ha), the gross and net fish yields were 14 452 and 11 984 kg/ha, respectively (75 times more than the 1984 level).

Table 5. Comparative studies of the water quality in the experimental reservoirs and ponds with a fish yield of 500 kg/ha.

Location and Date	pH	Alk (mg/L)	Ca^{2+} (mg/L)	Nitrogen Total (mg/L)	NH_4^+ (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	Phosphorus Total (mg/L)	PO_4^- (mg/L)	SiO_2 (mg/L)	COD	Fe^{3+} (mg/L)	Bacteria (10^6/L)
Fengchekou reservoir													
July 1985	8.25	19.5	3.55	0.588	0.04	0.004	0.146	—	trace	10.95	4.32	0.05	1.7
Oct 1985	7.2	23	3.60	0.75	0.25	0.008	0.142	0.26	—	13.7	5.68	0.30	1.87
7 Aug 1989	6.6	22	7.01	—	1.80	0.010	0.140	—	—	10.0	6.04	0.07	2.76
Before development	6.3	15	1.60	—	Trace	0.005	0.450	—	—	13.0	1.36	0.08	0.38
Wuxi reservoir													
6 Sept 1989													
surface	6.7	3.6	22.04	—	0.80	0.010	0.20	0.15	—	4.0	6.24	0.08	9.28
bottom	6.7	3.9	14.53	—	1.40	0.010	—	—	—	4.0	5.60	0.35	2.92
Tantangyong pond													
Oct 1985	7.32	129.5	40.10	1.20	1.20	0.110	2.575	0.315	—	14.5	9.32	0.825	0.91
Hufuzhen farm													
23 Aug 1989	7.30	66.0	23.04	—	0.40	0.120	0.16	0.06	—	6.0	5.52	0.15	6.08

Note: COD = chemical oxygen demand.

Table 6. Comparative studies on plankton, benthos, and primary productivity in Fengchekou reservoir and Tantangyong pond.

Location and Date	Weather	Primary productivity (g O_2/m^2 per day)	Plankton		Zooplankton				Benthos biomass	
			10^5/L	g/m^2	Protozoa (no./L)	Rotifera (no./L)	Cladocera (no./L)	Copepoda (no./L)	no./m^2	g/m^2
Fengchekou reservoir										
2 July 1985	Cloud, rain	5.53	267.5	21.36	5 584	315	0.5	1.1	1 623	4.586
15 Oct 1985	Clear, cloud	11.71	189.79	50.18	9 761	823	0.7	1.0	55	0.09
Original deposit	Clear	—	—	—	1 390	19	0.125	0	—	—
Tantangyong pond										
3 July 1985	Rain	3.45	185	14.16	5 313	760	0.5	0.4	260	1.803
16 July 1985	Cloud	1.55	105.58	5.19	7 317	421	0.4	0.2	2 161	3.393

Survival Rate and Stocking Efficiency

Because all experimental reservoirs were drained during final harvest, the catching rate was usually taken as the survival rate of stocked fishes. The abundance of dissolved oxygen (>5 mg/L), and the high conversion rate of food and manure in the reservoirs, meant that all the stocked fish had better growth and higher survival rates each year.

The average stocking efficiency was 4.28–4.68 in reservoirs with a fish yield of more than 7 500 kg/ha. However, stocking efficiency decreased with increasing stocking size. When the stocking sizes were 27.0–37.6, 38.6–82.5, 88.30–166.6, and 173.5–314 g, the stocking efficiency was 10.61–10.99, 7.96–4.95, 5.34–4.99, and 2.65–3.39, respectively. To reduce stocking weight and production cost, and meet the market demands, it was better to harvest the fish within one growing season. The optimal stocking size was about 70–100 g (Table 7).

Food and Manure Conversion Rate

The experimental results from Fengchekou, Guanmenchong, and Xiyangshan reservoirs indicate that to produce 1 kg of fish in the initial development stage of an oligotrophic reservoir requires: 1.58 kg of commercial food (or 4.3–4.4 units of rapeseed cake); 8.28 kg of green fodder; 1.88 kg of animal manure (equivalent to 10.14 kg stable manure); 0.06 kg phosphate fertilizer; 0.27 kg quicklime; and 0.242 kg fingerlings (Table 8). The food and manure conversion rate can be gradually increased every year with increases in feeding rate and manuring intensity.

Discussion and Summary

The ratio between land area and water area in small reservoirs is usually above 10:1 and the water depth is about 3 m. However, the ratio between land area and

Table 7. The annual changes in stocking sizes and stocking efficiencies[a] in the experimental reservoirs.

Reservoir	1985	1986	1987	1988	1989
Stocking size (g)					
Fengchekou	38.6	82.5	130.6	156.2	101.6
Guanmenchong	27.0	163.2	190.0	239.9	173.5
Xiyangshan	N[b]	314.0	37.6	166.6	120.1
Dashanwu	N	61.8	88.3	80.8	78.0
Wuxi	N	N	96.9	82.3	47.4
Stocking efficiency					
Fengchekou	8.0	5.0	4.3	4.3	3.8
Guanmenchong	11.0	3.9	3.8	3.1	2.7
Xiyangshan	N	3.4	10.6	4.5	4.2
Dashanwu	N	5.5	5.3	7.3	7.5
Wuxi	N	N	3.8	6.1	5.9

[a] Stocking efficiency = Harvest (kg)/Stocking (kg).
[b] N = No integrated practices.

Table 8. Food, manure, and fingerlings needed for producing 1 kg of fish in the experimental reservoirs.

	1986	1987	1988	1989	Average
Commercial food (kg)	1.66	1.98	2.28	1.46	1.83
Green fodder (kg)	7.97	7.26	5.00	3.92	5.56
Stable manure (kg)	9.38	5.69	8.94	13.41	9.91
Phosphate fertilizer (kg)	0.155	0.141	0.084	0.082	0.106
Converted into rapeseed cake (kg)	4.42	4.21	4.30	3.71	4.18
Quicklime (kg)	0.220	0.056	0.110	0.085	0.108
Fingerlings (kg)	0.233	0.213	0.216	0.215	0.219

water area in the experimental reservoirs was 46.8:1, and the average water depth was 4.1 m. Compared with fish ponds, with a ratio of 0.1–0.5:1 and a water depth of 1.0–3.0 m, the ecological conditions in the reservoirs were totally different. The essential factor limiting fish production in these oligotrophic reservoirs was a shortage of natural food organisms. To increase fish production in reservoirs, particularly in oligotrophic reservoirs, and to reduce production costs, integrated fish farming was adopted.

From our results, it can be extrapolated that for every 1 ha with an annual fish yield of 7 500 kg, 11 850 kg of commercial food, 62 100 kg of green fodder, 76 050 kg of stable manure, 450 kg of phosphate fertilizer, 2 025 kg of quicklime, and 1 807.51 kg of fingerlings would be needed. Because of the poor soil fertility of oligotrophic reservoirs, it is recommended that every 1 ha of water surface be supported by 1 ha of crop land and 45 pigs or 450 fowl. As the reservoirs were further developed and sediments were deposited, the amount of manure needed each year declined. At present, less than 4.0 units of rapeseed cake is required. If primary productivity and other factors are excluded, the conversion rate of food and manure in small reservoirs was 20–30% higher than in ponds.

There are some concerns about adopting intensive loading of food and manure: loss of energy during irrigation and water discharge; pollution of the environment and drinking water (Lu 1988); and shortage of a reliable supply of low-cost food and manure. Some energy was lost during irrigation and power generation. However, this may accelerate material circulation and promote the mass reproduction of aerobic bacteria. For example, in Wuxi reservoir, the input per hectare of water surface in 1989 was 95.52 t of animal manure (about 715.84 t of stable manure) and 24.64 t green fodder. The chemical oxygen demand (COD) of the surface water was 6.24, and the bacteria level was 9.28×10^6 cells/L; whereas, the COD of the bottom water was 5.60 and the bacteria level was 2.92×10^6 cells/L. These levels were all higher than those in high-yield ponds. However, the nitrite level was only 0.01 mg/L, which was 10% that of fish ponds. Therefore, it is safer to apply manure in reservoirs because organic sediments are not deposited to the same extent, and no "energy trap" is created. Besides, the higher conversion rate of both food and manure would sufficiently compensate for the loss of energy. Therefore, intensive loading of food and manure has greater potential for the development of small reservoirs.

Integrated development of reservoir fisheries is a field that involves many areas of expertise. It is different from pond culture, and its ecology must be studied and clarified. There are about 80 000 small reservoirs with total culturable area of

467 000 ha, and 6 million minireservoirs in China. The experimental results achieved so far may provide an important scientific basis for the further development of Chinese reservoir fisheries.

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Chen, J. 1982. Evaluation on the productivity of reservoir fisheries. Water Conservancy Fisheries, 1 (in Chinese).

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Discussion: Section 4 — Culture Techniques

Cage-culture practices in reservoirs are increasing in all countries in Asia; so too are the associated problems. Problems that are common to most countries in Asia are the unavailability of fingerlings of the proper size at the proper time and the increasing incidence of disease. The need for more research, particularly on husbandry aspects, and on the returns from feeding and nonfeeding practices were discussed. Unfortunately, the data that are available do not permit direct comparisons, and this was recognized as a possible area for future research. It was also felt that, whenever tilapiine species are cultured, it would be desirable to stock only males, sexed externally. This should not be a problem for the sizes of fingerlings stocked.

The importance of using cage culture for the employment of persons displaced due to impoundment was discussed, and the problems were highlighted. It was pointed out that this approach has been successfully adopted in the Sanguling reservoir in Indonesia, where the displaced persons, became better off as cage culturists than as "shifting cultivators."

Adverse environmental effects due to cage culture, particularly excessive phosphorus loading, were considered. It was pointed out that studies on intensive cage culture of salmonids have shown that nearly 75% of the nitrogen and phosphorus in feeds are lost to the environment (Folke and Katusky 1989) and that over a period this could result in very adverse effects. The case in Indonesia, where semi-intensive cage culture resulted (possibly) in sizeable populations of wild fish being attracted around the cages and being harvested as a "by-catch" was cited as a possible means of minimizing the effects of phosphorus and nitrogen loading, and providing an additional source of high-quality animal protein. Research on estimating and harvesting the "by-catch" due to cage culture practices was recognized as a priority research area at the first reservoir fisheries workshop.

Folke, C., Katusky, N. 1989. The role of ecosystems for a sustainable development of aquaculture. Ambio, 18, 234–243.

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The major research topics on reservoir fisheries in Asia discussed here are limnology, changes after impoundment, fisheries management and modeling, and culture techniques. As well as the papers prepared by the researchers, summaries of the discussion sessions and a set of recommendations made by the workshop participants are presented here. The recommendations encompass the research needs for developing reservoir fisheries in Asia but are relevant to developing countries elsewhere. Of the 25 papers, 9 deal with practices in the People's Republic of China, most of which are only now becoming known to researchers outside that country.

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