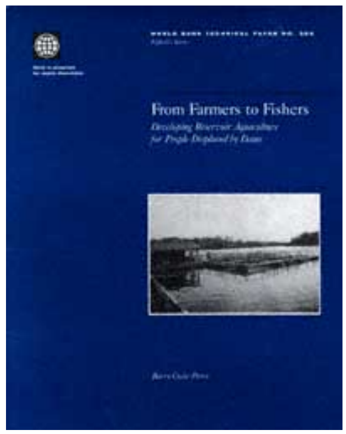

From Farmers to Fishers

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Developing Reservoir Aquaculture for People Displaced by Dams

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Cover photo: A raft of floating cages used for bighead carp culture, with guard house, in Durian Tungal Reservoir, Melaka, Malaysia. From "Cage and pen fish farming: Carrying capacity models and environmental impact." Food and Agriculture Organization of the United Nations, 1984.

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Contents

Tables

Foreword

Sustained population growth in developing countries has led governments—with the support of international financial institutions—to increase their efforts to provide electric power and irrigation water by harnessing rivers. The need for hydropower and irrigation has long been considered more important than the effect of these efforts on downstream fauna or the disruption of the livelihoods of millions of people in flooded areas. Fish and other aquatic life that could have been preserved with appropriate technologies have been lost forever, and many resettled farmers have not fully adapted to the changes forced on them.

Progress has been made in applying existing and new technologies—including fish ladders, elevators, and hatcheries—to prevent the damage to aquatic life that results from the construction of large dams. But until recently little had been done to deal with the effects large dams have on people, a far more important problem.

The lack of an integrated management approach for large bodies of water has prevented most planners and reservoir authorities from considering using the water for purposes other than hydropower or irrigation. But the Indonesian government, assisted by the World Bank and the International Center for Living Aquatic Resources Management, has been giving displaced farmers a way to rebuild their lives: shifting from rice and cassava farming to fish farming, using the water that flooded their land.

The success of the fish farming efforts in the Saguling and Cirata Reservoirs in Java attests to the potential for creating employment in reservoirs that are in place and under construction around the world. The World Bank will continue to emphasize the need to adopt an integrated approach to the use of large reservoirs during project planning—to ensure that these projects are environmentally sustainable and improve the living standards of the people affected. The search for new technologies will not cease until a sound balance is struck among the needs to raise living standards by expanding supplies of electric power and irrigated land, to protect and enhance the environment, and to improve human settlements in the flooded areas.

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Preface

Although the development of fish cage culture technology in the Saguling and Cirata Reservoirs in Java, Indonesia, was motivated by the displacement of more than 100,000 people by the flooding of the reservoirs, the lessons learned go beyond the issue of involuntary resettlement. The development of a technologically, economically, and financially viable fish culture system in Indonesia—a coordinated effort by the Directorate of Fisheries, Padjadjaran University in Bandung, the International Center for Living Aquatic Resources Management, and resettlement specialists from the World Bank—was made possible by adapting cage culture technologies from other Asian countries (such as Nepal) and by applying research to develop approaches that suited the reservoir conditions and the social fabric of the displaced farmers and communities. Because of this approach and the results it yielded, this effort has far−reaching implications.

If the work on the Saguling and Cirata Reservoirs were to remain merely a bibliographic reference on resettlement issues, the effort expended in preparing this paper and its companion video and instructional manuals would be a sunk investment. The World Bank and other development agencies need to take an active approach, one that leads to the replication of this experience while taking into account the many variables that differentiate large reservoirs around the world.

In many heavily populated areas the main factors motivating reservoir fisheries development are similar to those in Indonesia. But in many others (especially semiarid, low−density areas) the main factors would be employment generation, domestic fish supplies, and export of value added fish products.

The Betania hydropower reservoir in the Department of Huila, in Colombia, is a good example of fish cage culture development under a different set of conditions. Before flooding, the area was used by large land owners for extensive cattle grazing. Working closely with the reservoir authority, private entities planned the development of a tilapia cage culture model based on technical packages from Asia. The high demand for fish in the domestic market, particularly in Bogota, has helped sustain this effort.

In other places reservoirs may create new employment opportunities for subsistence farmers or for communities in which development options are limited or absent because of semiarid conditions. And if the reservoirs are used for irrigation, there would be an added bonus for downstream fields because fish waste enriches water.

There are hundreds of thousands of hectares of large reservoirs around the world. Although not all of them may be suitable for fish cage culture, the potential for creating jobs, raising incomes, increasing domestic fish supplies, and exporting value added fish products justifies an active role for development institutions and governments in developing integrated use plans for large reservoirs.

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At the World Bank, I'd like to give special thanks to Scott Guggenheim, who made many invaluable contributions to this project and related work in all phases of its evolution. Eduardo Loayza, Guy Le Moigne, Ron Zweig, Gloria Davis, and Michael Cernea at the Bank have also given invaluable assistance to me and to this work. The World Bank provided funding to develop a video on the fisheries ecosystems in Indonesian reservoirs, titled "Farming the Waters: Java's Blue Revolution" (available from the World Bank, Environment Department, Social Policy and Resettlement Division, 1818 H Street N.W., Washington, D.C. 20433).

At the International Center for Living Aquatic Resources Management (ICLARM), special thanks are due to Ian Smith, Roger Pullin, Jay Maclean, John Munro, Catalino de la Cruz, and Harlan Lampe for their expert assistance in this project.

Abstract

Hydropower and irrigation projects involving reservoirs can displace thousands of people from their traditional lands and deprive them of their livelihoods. If poorly planned, they can also lead to environmental degradation. Solutions to these problems must be found—solutions that are technically feasible, sustainable, environmentally appropriate, and acceptable to the people who are resettled.

Such solutions demand an ecological view—a view of reservoirs as ecological resources with far more value than as mere water storage units. The formation of a reservoir is a dramatic reordering of nature that creates a suite of complex, dynamic aquatic ecosystems. With proper planning, these new ecosystems can make potentially much more valuable contributions than those to national energy or to agricultural production. Indeed, they offer to the people who can adapt to living and working with them new opportunities for employment, and they can dramatically increase the production of aquatic protein.

This paper explains how the planned, integrated development of fisheries ecosystems in reservoirs not only can mitigate the negative social consequences of dam construction, but also can enhance the economic benefits from hydropower and irrigation projects in many developing countries.

The use of integrated reservoir fisheries and aquaculture development as a tool in large−scale resettlement and environmental rehabilitation has received little attention despite reports from a growing number of projects showing unexpectedly high returns from fisheries. In some years the total income from fisheries in reservoirs has exceeded the income generated from electricity sales.

The Saguling−Cirata reservoir project in West Java, Indonesia, was the first to demonstrate the potential of a planned, "ecosystems" approach to resettlement fisheries. This environmentally oriented resettlement effort fully utilized the new water surface for aquaculture and capture fisheries and developed supporting production, economic, and marketing infrastructure. More new jobs were created in the support industries for reservoir fisheries than in the fisheries themselves.

The development of fisheries is complex, however, since it requires a great deal of preparation and planning not only for the water−based fisheries systems, but also for the land−based infrastructure, seed, feed, and other market and agricultural support systems that are vital components. But as the Saguling−Cirata project shows, if the right conditions are in place, the planned development of reservoir fisheries can be an effective way to create alternative livelihoods for people displaced by a reservoir, greatly enhancing the economic and social benefits from hydropower and irrigation projects.

Executive Summary

Many nations have few or no indigenous energy sources and limited funds to increase oil imports or develop nuclear power. With both coal−fired and nuclear power plants increasingly seen as likely to impose unacceptable economic and environmental costs for present and future generations, hydropower has emerged as the best alternative for the vast majority of developing countries.

Today, the technical and engineering aspects of river basin development projects are straightforward. What deters the development of hydropower resources are the persistent problems of resettlement and the economic and social disruption that accompany the creation of a new storage reservoir.

Viable solutions to these problems must be found—solutions that provide productive new enterprises and alternative livelihoods for the hundreds of thousands of people displaced by reservoirs and that mitigate environmental degradation caused by poorly planned hydropower projects. These solutions must be technically feasible, sustainable, environmentally appropriate, and acceptable to the people who are resettled.

Such solutions require a new view of the situation, one that treats reservoirs not just as water storage units, but as far more valuable ecological resources. The formation of a reservoir is a dramatic reordering of nature that creates a suite of complex, dynamic aquatic ecosystems. With proper planning, these new ecosystems can make potentially much more valuable contributions than those to national energy or, through irrigation, to agricultural production. Indeed, they offer to the people who can adapt to living and working with them new opportunities for employment, and they can dramatically increase the production of aquatic protein.

Economic and Social Benefits of Reservoir Fisheries Development

The successful fisheries ecosystems developed for farmers resettled in the Saguling−Cirata reservoir project in West Java, Indonesia, serve as a model for the use of integrated reservoir fisheries and aquaculture development in large−scale resettlement and environmental rehabilitation. The Saguling and Cirata hydropower reservoirs, flooded in 1985 and 1988, covered an estimated 12,300 hectares, including 5,783 hectares of rich rice−growing land, with a financial loss to farmers of an estimated $5.21 million a year. But by 1993 fish cages in the reservoirs were producing more than 10,000 tons of fish a year, worth an estimated $10 million.

Such projects have received little attention despite reports from a growing number of them showing unexpectedly high returns from fisheries. Indeed, in some years the income from fisheries in reservoirs has exceeded the income from electricity sales. For example, in 1978 the Ubolratana Reservoir in northeast Thailand produced fish from capture fisheries worth 40 million baht, while electricity sales generated just 30 million baht.

The Saguling−Cirata project in Indonesia was the first to demonstrate the potential of a planned, integrated ecosystems approach to resettlement. This project fully utilized the new water surface for aquaculture and capture fisheries and developed

supporting production, economic, and marketing infrastructure. Reservoir fisheries were developed as part of a regional development effort promoting local recycling of resources from one productive enterprise to another and the creation of complex interactions among enterprises.

Among the people resettled in the SagulingCirata project there was widespread acceptance of the change from land−based to water−based livelihoods. In surveys the displaced people evaluated cage aquaculture as easy, enjoyable work allowing much leisure time, in contrast to the back−breaking toil they had been accustomed to in their rice and vegetable fields. Among the displaced people who had increased their incomes and status since resettlement, most were involved as owners or workers in water−based businesses.

The integrated fisheries systems increased the number and variety of jobs and the number of higher−paying jobs. This occurred in an area where the lack of growth in employment in rice and vegetable production had been a major concern in the 1970s and where the capacity of rice−based agriculture systems to absorb more labor had been projected as virtually nil.

More new jobs were created in the spin−off—or support—industries than directly in the new fisheries enterprises. Of the thousands of people displaced by the flooding of the Saguling and Cirata Reservoirs, an estimated 7,600 were employed directly in the reservoir fisheries enterprises by 1992, and 22,80030,400 in the new support industries created.

The development of reservoir fisheries was accompanied by new forms of community organization that are knowledge−based, relying on skills and education. Fisheries cooperatives, schools, a labor service, and a fish farmers organization are active.

Ingredients of Success

The success of the development of aquaculture in reservoirs in West Java, Indonesia, is due to four main factors:

The presence of large, unsaturated markets in a densely populated region where freshwater fish has traditionally been the main source of animal protein, consumer recognition of the product is high, access to capital is good, and fish marketing and transport infrastructure is excellent.

Adequate availabilities of seed fish (fingerlings) and feed.

Farmers' sophisticated traditional knowledge of fish and fisheries systems.

The ready availability of capital from compensation money and other sources, allowing the displaced people and others to make immediate investments in new fisheries enterprises.

Reservoir aquaculture schemes developed, in their initial phases, low−cost cages appropriate to, and conserving of, available capital. They were then intensified as capital availability and market demand increased. For the poorer segments of society, mini−cage or subsistence systems and no−feed cage culture systems have been successful in Indonesia, Nepal, and the Philippines. For entrepreneurs with more capital, semi−intensive and intensive systems (single and biculture cage systems) have proved profitable. There is a wide range of cage aquaculture systems. To ensure success, systems where the "seed, feed, and need" are clearly present must be selected for development, and a "market−driven technological approach" is needed.

Successful reservoir capture fisheries schemes in Asia use self−perpetuating species with short life cycles that can be heavily fished with low−cost gear and are owned and managed by local people. Successful species in reservoir capture fisheries have been the tilapia (Indonesia, Sri Lanka), freshwater sardines (clupeids) (Thailand), and indigenous carp (India, Sri Lanka). Selective fishing of predators has increased total yields and allowed the manipulation of reservoirs' fish species composition in order to build large populations of herbivorous and omnivorous fish that have contributed substantially toward meeting human needs. Dam operations play an important part in the success of reservoir fisheries. The extent and timing of changes in water levels in a reservoir and the size of the minimum pool of water maintained affect the production and yield of both capture and culture fisheries systems.

Recommendations

Development planning for integrated fisheries ecosystems to support resettlement and social and environmental rehabilitation should be included in the policy and operational guidelines for all water resource projects in developing countries, especially for dam−reservoir, irrigation, watershed, and river basin development projects. Such planning should also be included in regional development plans wherever World Bank−financed projects affect water resources and riparian ecosystems.

The rehabilitation of natural ecosystems damaged because of water resource development projects, and the adaptation of the displaced population to a new "fisheries culture," should be seen as a process and broken down into specific phases, with objective milestones of progress in each phase. To ensure that these milestones are met, an effective monitoring and reporting system should be established. It is recommended that the environmental impact assessments routinely required at the initial stages of hydropower and irrigation projects should be expanded to cover social and resettlement concerns. These assessments should be conducted regularly as part of a continual monitoring process the first 10 years after the impoundment of a reservoir.

Where there are major water resource development projects with social and environmental impacts, multidisciplinary river basin commissions need to be formed that include fisheries experts and planners. These commissions should be funded under project loan agreements, remain in operation for a minimum of 10 years after project loan agreements are signed, and be responsible for contributing to the development and management of the fisheries ecosystems approach as part of the rehabilitation and monitoring process.

Introduction

Many developing countries need to dam rivers to develop modern irrigation systems and hydropower in order to meet the urgent food and energy needs of their burgeoning populations. In many areas agricultural development is impossible without reliable water supplies during the dry season. And for nations lacking oil resources, hydropower provides a domestic energy source that avoids the potential long−run health and safety effects of coal−fired and nuclear power plants. As a result, the number of multipurpose dams is increasing rapidly, especially in the developing countries of the humid Tropics. The International Commission on Large Dams records more than 37,000 large dams (those with reservoir surface areas greater than 10 square kilometers) in operation worldwide (ICOLD 1992). The number of smaller dams is unknown, but it is likely to be in the hundreds of thousands.

Although hydropower avoids the long−term consequences of polluting or potentially more dangerous energy sources, the problems posed by resettlement and loss of traditional lands that accompany a new reservoir are long−lasting. New reservoirs often flood rich agricultural land that has been settled for generations. The unfamiliar new water ecosystems often exacerbate conflicts pitting local people against national interests, rural selfsufficiency against urban demands, and traditional against modern development models. Figure 1 shows the complex web of effects of dams and reservoirs.

There are few simple solutions to the perplexing social and environmental problems of water development projects. Indeed, in many parts of the world it is these problems, not technical or engineering problems, that are the main obstacles to increased hydropower development.

But hydropower and irrigation development projects contain possible solutions to the problems they create. Reservoirs are more than just water storage facilities; they are also complex, dynamic aquatic ecosystems. These new ecosystems offer vast, virtually untapped opportunities to dramatically increase the production of aquatic protein, especially in Asia, and to generate new employment. Yet empirical studies of the potential of reservoir fisheries to help ease the problems of resettlement and assist in rehabilitating the natural environment are surprisingly rare, despite the obvious attractiveness of this solution. In Asia development of reservoir fisheries was not widely considered outside of Sri Lanka until the mid−1980s.

As dam and reservoir construction speeds along in developing countries, the vast majority of water development projects—whether for irrigation, drinking water, or hydropower—still fail to plan for fisheries development. Project managers rarely call on fisheries experts to do more than assess possible environmental impacts. When fisheries experts are asked to play a larger role, they are often involved much too late in the process, as part of the "cleanup crew" for resettlement programs gone awry. Too often, fisheries are an afterthought that, at best, must fit into power or irrigation schemes as a secondary benefit. As a result, reservoir fisheries often fail.

Fisheries that develop spontaneously in project reservoirs or as an afterthought to water develop−

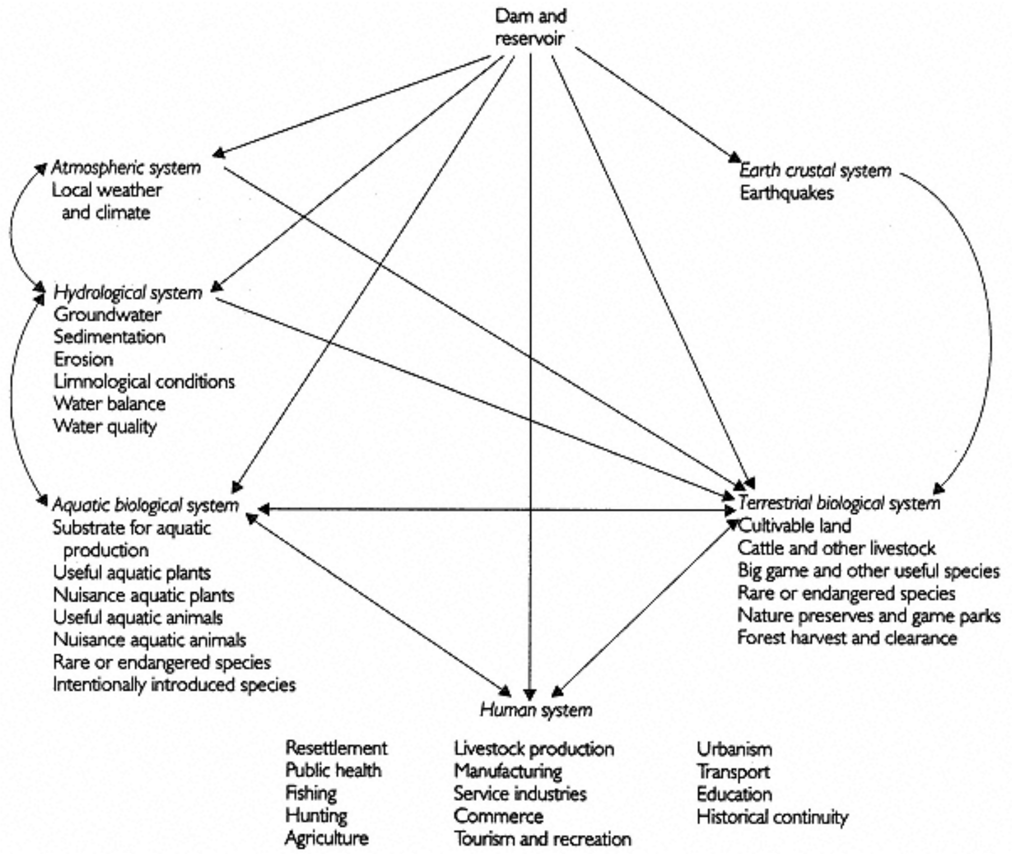

Figure 1
Dams and reservoirs affect a range of natural systems—including the human system
Source: Pantulu 1979.

ment projects tend to be low yield. But that is not always the case. Reports from a growing number of projects that provided little or no additional capital for developing and managing new fisheries operations have shown unexpectedly high returns from reservoir fisheries. In some years large reservoirs in Asia and Africa have generated more income from fisheries than from electricity sales.

Although reservoir fisheries offer an attractive solution to the problems of resettlement, making them work can be extraordinarily difficult. For traditional people whose lives are inextricably linked to the land, the shock of losing their homes and land, combined with the appearance of a new body of water in their midst, can be unbearable. There is an urgent need to identify acceptable means of easing the transition from a "terrestrial" to a "water" society. Successful transitions remain the exception. What is needed is to develop indigenous, interdisciplinary management teams capable of assessing, planning, implementing, and monitoring an integrated set of technical, social, and operational solutions to the complex problems of local resettlement—difficult tasks under the best of conditions. Also needed are more intensive project planning and attention to process. If people feel left out of the process of development, they will not participate in the changes taking place.

This paper examines the development and management of integrated reservoir fisheries and aquaculture as a strategy for creating new jobs and business opportunities for displaced people. Few

such reviews have been done to verify the employment and production potential of integrated reservoir fisheries ecosystems. Nor has any road map of the technical and operational requirements been developed that lays out the range of possible aquatic protein production systems for development. Moreover, little applied social research has been done on ways to help smooth the transition from land−based livelihoods to water−based ones for resettled people.

The paper reviews key technical, social, economic, and institutional concerns in developing fisheries as a means of support for people affected by large−scale resettlement projects. These concerns are particularly relevant in Asia, where reservoirs are growing in number. The region's reservoir surface area will expand by an estimated 500600 percent by the year 2000 if current plans to develop its vast hydropower potential proceed. In Cambodia, the Lao People's Democratic Republic, and the Philippines reservoir surface area could increase by more than 1,000 percent (Costa−Pierce and Soemarwoto 1987).

The paper makes frequent reference to a case study of the Saguling−Cirata reservoir fisheries resettlement project in Indonesia, one of the more successful and well−documented working models in Asia. The report reviews technical issues, and then sets out a practical ecosystems model of reservoir fisheries development. It emphasizes key issues, constraints, needs, and operational and managerial challenges faced in the Indonesian project and others, and details planning concerns for future projects in resettlement fisheries.

Engineering Issues in Reservoir Fisheries

To develop sustainable, productive fisheries, the requirements of fisheries ecosystems must be demonstrated to engineers so that they can be taken into account in the operations of dams. The water in a reservoir can be envisioned as a series of layers (Bernacsek 1984). Dam engineers have much control over the presence or absence of these water layers and their size, features that have fundamental implications for the sustainable development of reservoir fisheries. This section provides an overview of reservoir engineering issues—the types, designs, and operations of reservoirs—as they affect fisheries.1

Types of Reservoirs

Dams are constructed to regulate a river by achieving control over the discharge of water. Regulation makes it possible to redistribute water from the rainy to the dry season (figure 2). Dams are associated with three types of reservoirs: storage, flood control, and multipurpose.

Storage reservoirs store water from the rainy season for downstream use in the dry season. Storage behind the dam reduces peak discharge during the rainy season so that water use is more or less uniform during the dry season. Reservoirs are kept near the normal upper storage level, and fluctuations in their surface area are small. Storage reservoirs are used mainly for irrigation and water supply.

Flood control reservoirs control the peak of the rainy season flood and prevent downstream flooding. They fill during the rainy season, and the water is used during the dry season. These reservoirs undergo large annual fluctuations in water levels and may be dry for part of the year.

Multipurpose reservoirs serve the functions of both storage and flood control. The objective is to control the peak flood wave and to attain greater dry season flow than is possible with storage reservoirs. Most modern reservoirs, and all those associated with the newer hydropower dams, are of this type. Flood control is achieved by drawdown of water levels in the rainy season, and storage is accomplished by engineering adequate reservoir size and depth.

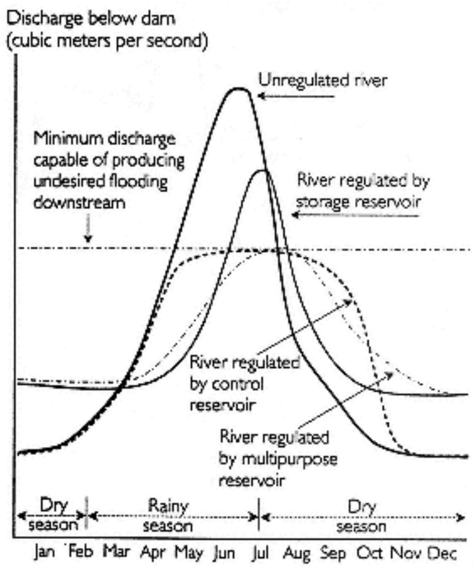

Figure 2
Regulation allows the redistribution of water from the rainy to the dry season
Source: Bernacsek 1984.

Dam Crest Elevation

The dam crest elevation—the highest elevation of the dam above sea level—determines the economics and the possible range of functions of a multipurpose dam project. Because it defines the size of a reservoir, it also determines potential fisheries yields, as well as the area of land to be inundated and thus the resettlement needs. In addition to size, the dam crest elevation determines other morphometric characteristics of the reservoir, such as shape, water levels, and depth—important factors in the development of fisheries.

Economics drives the choice of the dam crest elevation. Hydroelectric engineers attempt to achieve the highest dam crest elevation possible so as to maximize the height of reservoir water levels above the turbines and thereby achieve the highest possible hydraulic head and electricity output (figure 3). Hydraulic head is the drop in elevation from the intake to the tailwater discharge. The drop in elevation produces hydraulic pressure across turbine blades, situated at an optimum intermediate elevation (Bernacsek 1984). Electricity production requires the continuous management of reservoir water levels to keep them above the normal minimum operating water levels of the dam. Maximum electric power generation is attained at maximum water levels.

Today, however, choices of dam crest elevations are not based simply on technical equations of power generation capacities or river basin morphology, geology, or engineering. Choices are also influenced by resettlement considerations, the amount of land to be inundated, and other social and political factors. For example, the proposed dam crest elevation of the Pa Mong dam in the Lao People's Democratic Republic was changed from 250 meters to 210 meters to reduce the estimated number of people who would be displaced in that country and in Thailand from 250,000 to 60,000. In Indonesia the dam crest elevation of the Saguling

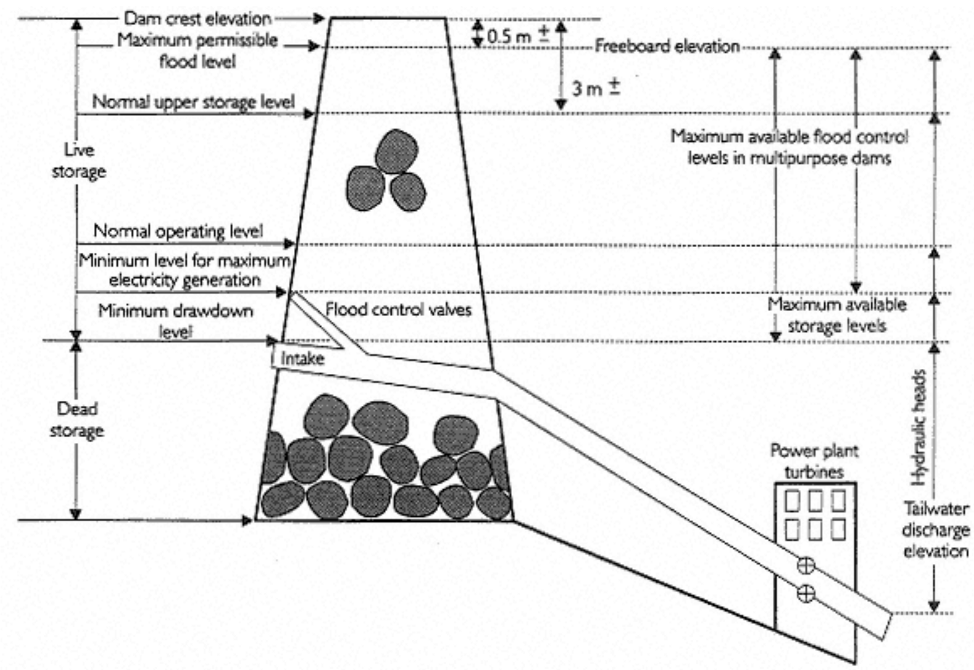

Figure 3
The dam crest determines the economics of a dam project
Source: Bernacsek 1984.

dam was lowered from 650 to 645 meters to reduce resettlement. In Mozambique the dam crest elevation of the Cabora Bassa dam was lowered to prevent the inundation from extending into a neighboring country (Bernacsek 1984).

Drawdown

The two main factors in dam operation that have documented effects on reservoir fisheries production are the size and the rate of drawdown. Engineers use drawdowns to maintain water levels within limits specified to meet the primary goals of the dam (power generation, irrigation). Drawdown can result in highly erratic water levels and changes in the size of the minimum pool of water in the reservoir. The extent and timing of water level changes and the size of the resultant pool of water have important effects on fisheries.

Most Asian reservoirs are multipurpose hydropower and irrigation reservoirs subject to significant water drawdown. Bhukaswan (1980) has stated that the most important factor influencing fish production in Asian reservoirs may be fluctuations in water levels. In Sri Lanka De Silva (1985) found a positive correlation between reservoir water level and tilapia yields two years later.

Changes in water level affect nearly all aspects—structural and functional—of the aquatic ecosystem in reservoirs. Water level changes have both positive and negative consequences for fisheries. Positive changes include these:

If water levels are lowered after an unwanted aquatic species (such as a predator) spawns, the eggs and spawn of the species may be stranded, eliminating or reducing its population.

If water levels are raised, nutrients (such as cattle manure) washing from the dried areas of the reservoir's shallows (its littoral zone) may raise fish production by increasing the production of the aquatic ecosystem and thus the survival of new fish recruits.

If water levels are raised during the spawning season, fish spawning and recruitment may increase.

Negative changes stem primarily from lower water levels, which can:

Cut off fish migrations.

Strand fish, both during spawning and at other times.

Destroy spawning areas by uncovering them, leaving them to be trampled by animals and humans during the dry season.

Reduce or destroy fish habitats and spawning grounds, weed beds, and the supply of bottom (benthic) foods.

Rapid changes in water level are particularly dangerous, as they upset ecological balances between producer (food) organisms that feed higher−level consumers such as fish.

Engineers typically control reservoir water levels according to a design rule curve. Before construction of a modern, multipurpose dam, hydraulic engineers examine available data or collect primary data on riverine water flows, their seasonal variation, and the magnitudes of river flood cycles over as long a period as possible. Using information on seasonal flows and flood probabilities, engineers then construct design rule curves, which put strict limits on the upper and lower water levels to be maintained for the optimal economic operation of the dam.

In many developing countries there are insufficient data on flood levels (the maximum flood level is usually chosen at a one−in−10,000−years flood), so that a design curve must often be redone after the first few years of experience with a new dam. This lack of data is one reason that many dams have been over− or underdesigned, leading to, for example, insufficient inflows because flood cycles were overestimated, or vice versa.

Bernacsek (1984) has pointed out that the design rule curve is more a safety feature to protect against natural variability in inflow and userdependent variations in outflow than a precise guide to the water levels that should be maintained at any one time. He argues that incorporating the needs of fisheries into reservoir management requires a shift from using the design rule curve as a safety valve toward using it as an operational target for water levels. In this management approach a dam operator would attempt to maintain a particular water level at a specific time. Because that would make it easier to

predict water levels, fisheries planners would be better able to forecast yields and determine potential benefits for end users. Nevertheless, the bottom line for fisheries planners is that it is impossible for engineers to maintain a reservoir at a constant level under current operational guidelines.

Bottom Clearing

For engineering purposes, only the bottom areas near the spillway and sluice gates of a dam must be cleared. But for fisheries the issue of whether to undertake the major effort and expense of clearing the reservoir bottom is much more complex.

Leaving the reservoir bottom uncleared makes the use of many types of fishing gear, such as trawls and seine nets, impossible. But leaving organic materials such as trees, brush, and grasses on the reservoir bottom provides essential habitats for fish and for aquatic organisms on which fish feed.

Ploskey (1985) suggests that bottom clearing is preferable for reservoirs in North America, but recommends retaining some uncleared areas to provide extra habitats for fish. For African reservoirs, Bernacsek (1984) believes that the long−term benefits of bottom clearing for fisheries activities outweigh any benefits from keeping trees and other vegetation as habitat and food for fish.

De Silva (1988a) reviewed the effects of bottom clearing in Asian reservoirs and identified both negative and positive consequences. He found that bottom clearing provides extra niches for fish, increases the role of birds in predation and nutrient cycling, and reduces erosion and siltation. But he also found that it impedes fishing, leads to eutrophication and adverse effects on water quality, and results in the leaching of toxic organics such as trihalomethanes.

De Silva concluded that although quantitative evaluation of the effects of bottom clearing is impossible at present, there is convincing evidence that fish stocks are larger where the reservoir bottoms have not been cleared. This finding would lead to a recommendation to keep some areas uncleared to increase fish populations and yields. No scientific or economic studies are available that would help in formulating specific recommendations on what percentage of reservoir areas should be kept uncleared in the Tropics, although a number of studies address this issue in the temperate zone.

Position of Reservoir Outlets

In the Tropics the position of a reservoir's outlet strongly influences the reservoir's nutrient content, oxygen conditions, and fish production (figure 4). Positioning the outlet in the bottom waters (hypolimnion) of a reservoir helps avoid thermal stratification. If a reservoir is permanently stratified, inflows of warm river water will course through only its surface waters, leaving its bottom waters unaffected (see section below on turnover events). A bottom outlet enables dissolved oxygen to penetrate to the depths of the reservoir, expanding the productive area for aquatic life and leading to higher fisheries production (Sreenivasan 1986).

Multiple outlets can offer more flexibility in operation and avoid conflicts between uses of the reservoir water. Surface and bottom outlets can be

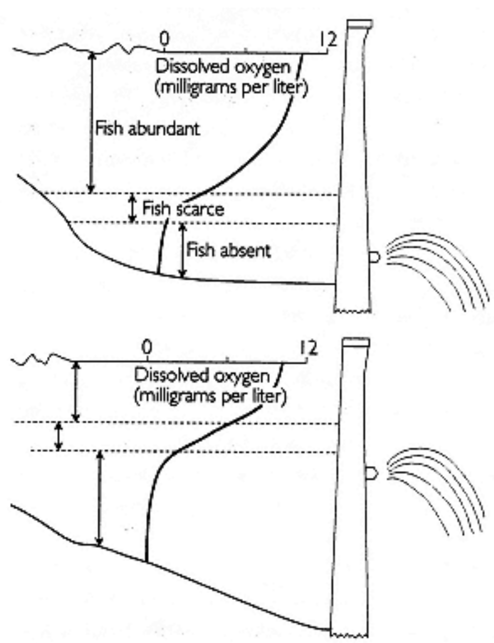

Figure 4
Bottom outlets lead to deeper oxygen penetration and higher

fish production
Source: Sreenivasan 1986.

used for flood control or irrigation, while mid−level outlets can be used for drinking water to avoid excessive iron and hydrogen sulfide and to prevent a need for excessive filtration and other problems caused by using algae−laden surface waters.

Reservoir Turnover Events

In the lowland Tropics the water column of reservoirs is essentially mixed from top to bottom. Wind action can stir the water column to nearly the depth of the bottom. At altitudes above 200300 meters in the Tropics or at increasing latitudes from the equator, reservoirs are thermally stratified—that is, the reservoir water is stratified in layers of differing density, with warmer, less dense water overlying colder, heavier water. Sreenivasan (1970) showed that in India lowland reservoirs north of 14° north latitude were stratified, whereas south of this latitude only reservoirs at elevation were stratified.

Where stratification occurs, bottom waters become laden with suspended sediments and nutrients from watersheds and the surrounding basin while surface waters become nutrient−poor. As sediments and nutrients accumulate in bottom waters, dissolved oxygen plummets to zero and hydrogen sulfide reaches toxic concentrations. Hydrogen sulfide has reached such high levels in the bottom waters of some reservoirs that it has corroded turbines and other structures.

Many hydropower reservoirs in the Tropics are located at elevation in order to maximize hydraulic head to the turbines and increase power output. In reservoirs above 200300 meters annual turnover events can occur, in which toxic bottom water rises to the surface. Water column turnovers are initiated by a seasonal cooling of surface water to a temperature similar to that of bottom water or by the entry of cooler water from upland rivers or tributaries during heavy rains that sinks to the bottom (since it is cooler than surface water) and forces the bottom water to the surface. Turnovers are exacerbated by strong drawdowns.

Sudden turnovers in reservoirs have led to catastrophic fish kills, including losses of hundreds of tons of fish in floating cage aquaculture systems. The deoxygenated water and large quantities of hydrogen sulfide that rise to the surface suffocate nearly all aquatic life. Turnover events in the Saguling Reservoir in Indonesia during January—February 1993 killed 850 tons of fish (Sutandar 1993). In the Jatiluhur Reservoir, in West Java, Indonesia (at 94.6 meters above sea level), a turnover killed 1,560 tons of fish in aquaculture cages, causing losses estimated at 3.5 million rupiah (Rp) and putting an estimated 215 farmers out of business (*Suara Pembarvan,* Jakarta, January 10, 1996).

Indonesia has two distinct seasons, determined by its prevailing wind patterns: a dry season from April to August, when winds come from the southwest (or "Australian" direction), and a wet season from September to March, when northeast monsoon winds from the Indian Ocean buffet the nation. Since inundation in 1985, turnover events have occurred regularly in the Saguling Reservoir (650.5 meters above sea level) at the onset of West Java's upland rainy season. Turnovers have also affected the Cirata Reservoir, at 6° south latitude and 225 meters above sea level, but to a much lesser extent: in 1991, when 300 tons of fish were lost in Saguling, only 10 tons were lost in Cirata. In 1992, however, an unusually dry year with poor rains, no turnover events occurred in Saguling or Cirata for the first time since inundation (Effendi 1992).

Observations of turnovers during three rainy seasons in Saguling showed the following characteristics:

Conditions varied across the reservoir, with turnover occurring in one bay but not in others, perhaps because individual bays received cooler water from localized cloudbursts in the mountains.

Some turnovers seemed to be caused by the entry, at the onset of the wet season, of cool rainwater that caused bottom water displacement rather than surface cooling.

Strong drawdowns during the rainy season increased the frequency of turnovers.

Turnovers were followed by dense, blue−green algal blooms because of the movement of bottom nutrients to the surface.

Farmers who reduced stocking density in cages tended to survive even the worst of the turnover events.

Transition: From Tropical River to Reservoir

Damming a tropical river to create an artificial lake has dramatic effects on all parts of the former watershed ecosystem. The effects on the production and fertility of riverine fish species occur immediately after the new reservoir is filled and continue over the next 5—10 years. As the new aquatic ecosystem evolves, the biota respond—mainly to the operation of the dam and to the land use practices in the watershed. The direction of change in the new aquatic ecosystem can be managed in a positive way that is compatible with reservoir engineering operations—given adequate expertise, institutional will, and financial resources. For a new "ecosystems management" strategy to evolve, operational engineers and fisheries planners need to be concerned with water quality and siltation, vegetation, the distribution and composition of fish species, and changes in their production.

Siltation

Reservoirs receive large deposits of silt carried from the watershed by tropical rivers. In intact watershed and river ecosystems tropical rivers carry tons of silt and associated terrestrial materials to the coast, replenishing deltas and coastlines and contributing vital nutrients to coastal zone fisheries ecosystems. But excessive silt and nutrient loads due to uncontrolled development of watersheds can dramatically reduce reservoir storage capacities and set in motion nutrient cycles with destructive effects on fisheries. Several of the major Asian rivers have among the highest reported sediment discharge rates in the world (table 1; El−Swaify, Aryad, and Krishnarajah 1983). Some reservoirs in degraded watersheds in Bangladesh, India, and Pakistan have lost more than 60 percent of their storage capacity and become uneconomic in less than 50 years (Sreenivasan 1986).

How much silt a river carries depends on the erodibility of soils, the health of the watershed ecosystem, and especially the areal extent of human impacts on riparian and upland areas. Land uses in watersheds that have the most serious effect on siltation are deforestation; clearing of upland and riparian land for agriculture, especially shifting cultivation; nonpoint pollution from agriculture, especially nutrients and pesticides; overgrazing and trampling of soils and vegetation by animals; sand and other mining; and the use of heavy machinery in site preparation, clearing, and finishing.

The effects of erosion and siltation from degraded watersheds are particularly notable and concentrated during the rainy season, when large plumes of brown water and terrigenous matter can be seen entering reservoirs. Silt and soil particles retain large quantities of nutrients, which accelerate the growth of plant plankton (phytoplankton) and lead to plankton blooms. Under tropical conditions, this additional nutrient input leads to the development of enormous, thick, green scums of algae on the surface of reservoirs, cutting off light to the underlying water. Boom and bust cycles of plankton populations then occur, as algal growth becomes self−limiting because of light deprivation and the algae suddenly dies, depleting the water of oxygen and causing massive fish kills.

Table 1 Sediment discharge rates of selected Asian rivers

River	*Sediment discharge (millions of tons a year)*
Amur (Russia)	52
Haiho (China)	81
Yellow (Huangho) (China)	1,080
Yangtze (China)	478
Pearl (Zhu Jiang) (China)	69
Mekong (Vietnam)	160
Irrawaddy (Myanmar)	265
Ganges/Brahmaputra (Bangladesh)	1,670
Indus (Pakistan)	100

Source: Sreenivasan 1986.

The long−term economic viability of operations and the integrity of reservoirs as productive aquatic ecosystems depend on the management of land use in the watershed and upland areas. In Southeast Asia degradation of watersheds, proliferation of nonsustainable agricultural practices, and pollution due to urbanization and industrialization are the most serious threats to both reservoirs and coastal zones. Some commonsense recommendations for mitigating the severe degradation of Asian watersheds are to:

Develop afforestation methods as part of an integrated plan for rehabilitating river basin ecosystems.

Develop mixed grasses, vegetation, and tree crop agro−ecosystems that control erosion and provide viable livelihoods.

Control riparian erosion through buffer strips, planting combinations, or mechanical control methods such as riprap (stones lining stream banks).

Aquatic Vegetation

The second major concern in the transition from a tropical river to a reservoir is the accumulation of aquatic vegetation in the calm waters of the new lake. Most tropical rivers contain a plethora of aquatic vegetation that becomes trapped in the still waters of the new reservoir (the transition from a "lotic" to a "lentic" ecosystem). Reservoirs are nutrient and sediment traps. When aquatic vegetation makes its way into this environment, it undergoes explosive growth. A major economic and environmental problem can arise before it is even recognized that the process is occurring. Deep reservoirs with little shallow area (littoral zone) are largely free of weed problems. But shallow reservoirs with large littoral zones have huge problems with water hyacinth, water lettuce, and *Salvinia*.

Aquatic weeds can have severe effects on dam operations and fisheries. Infestations can be so thick that their weight undermines the foundation of the dam. Weeds can consume prodigious quantities of nutrients, leaving little for the development of an aquatic food web to feed fish. Aquatic weeds also interfere with fishing.

Controlling aquatic weeds is difficult once the problem gets out of hand. Millions of dollars have been spent on single control methods, whether chemical, biological, or mechanical. Water hyacinth control in the Saguling Reservoir, for example, cost the Indonesian State Electric Company an estimated $300,000 a year. Experience shows that control is possible only through an integrated approach combining mechanical means, community efforts, judicious application of chemicals, and biological control using the weeds' natural enemies (Pieterse 1977).

Changes in Ecological Balance

Damming a tropical river leads to three major changes that affect the ecological balance as a reservoir forms:

From a flowing water (lotic) ecosystem to a standing water (lentic) ecosystem.

From a benthic to a pelagic food web.

From a nutrient−poor ecosystem to a nutrientrich one.

In addition, dams may cause the extinction in a river of anadromous and other migrating fish and of fish requiring specific spawning grounds. In India, for example, the Indian shad (*Hilsa ilisha)* and the mahaseer (*Tor khudree)* have become extinct in the Cauvery River system (Sreenivasan 1986).

Tropical rivers generally are turbid and narrow in their upper and middle reaches. As a result, in most inland areas of Southeast Asia the predominant riverine fish species are tactile (as opposed to visual) feeders that depend on river bottom (benthic) food webs. There are few riverine fish with open−water (pelagic) life cycles or food webs (Fernando 1980; Fernando and Holcik 1982). Native carp species (family: Cyprinidae) that feed on bottom resources dominate the fish species composition of most rivers in the region.

Fewer fish species occur in reservoirs than in the original rivers, primarily because reservoirs have fewer habitats than rivers. In addition, the lower turbidity in reservoirs helps predators to be more effective in hunting prey. And a new fishery reduces populations of valuable species, leaving slowergrowing, less desirable fish (Wadjowicz 1964).

The change from a lotic to a lentic ecosystem leads to changes in the spatial distribution and food habits of native riverine fish species. A "toilet bowl" effect occurs in the transition from river to reservoir. Riverine fish species that normally inhabit shallow−water, benthic ecosystems seek similar depths and habitats in the new reservoir and choose the shallows near the shorelines. Species that cannot find suitable space, cannot adapt, or face new competition from species that they might be encountering for the first time are flushed out of the system and lost. In such situations the openwater (pelagic) zones can be nearly devoid of fish species. In addition, displaced people who resettle near the new lake often fish heavily in shoreline areas, depleting and destroying the remaining riverine fish populations.

The deposit of nutrients from a turbid, tropical river ecosystem into a nutrient sink (for example, a new lake ecosystem) causes a rise in fisheries productivity in the first few years after inundation. Balon and Coche (1974) describe this change in aquatic ecosystem as a four−phase process: (1) unbalanced fertility (or eutrophy), (2) vulnerable stability, (3) stabilization, and (4) maturity. A fifth phase, unbalanced eutrophy, occurs where there is nutrient pollution and adverse land use practices (figure 5).

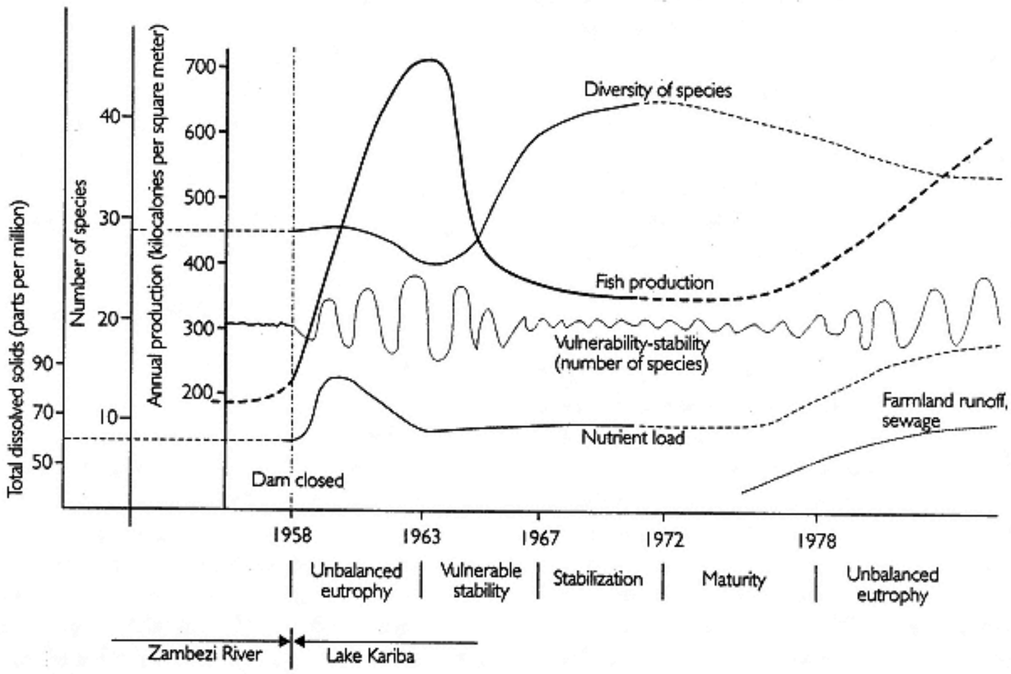

Figure 5
The ecosystem of a new reservoir undergoes several phases before maturity
Source: Balon and Coche 1974.

During the filling of new reservoirs nutrients are leached from soils and other organic matter, resulting in a fertile aquatic ecosystem. Successfully adapting fish species initially increase in population, and fish production rises. The initial burst in fish production during the first few years after inundation often is not sustainable. Fish production declines rapidly as the reservoir basin reaches its basal level of fertility. At maturity, fish populations and their food organisms become adjusted to the permanent fertility level of the basin and nutrient balances resulting from inflows, outflows, and runoff (Bhukaswan 1980).

Year to year, however, fish production patterns may differ greatly from these general outlines. Each reservoir has different nutrient inflows that vary according to dam management practices, rainfall and amount of runoff and river input, and additional nutrient loads from human activities. Outflows similarly can vary widely, depending on demand. Other factors also affect the fish yield of reservoirs (box 1). The challenge is to develop costeffective monitoring and management systems to ensure the optimal use of fisheries resources for human needs and for maximum economic benefit.

Predicting Capture Fisheries Yields in a New Reservoir

The combined influences of the age, size, depth, shape, catchment area, and hydrological regime of a reservoir largely determine its biological productivity. Fisheries management practices and human impacts (such as pollution) also affect a reservoir's productivity. The magnitude of the influence of these factors and the synergies among them are different for each reservoir. The challenge is to determine which physical or limnological factors exert an overriding influence on fisheries productivity under different seasonal regimes.2

To delineate predictive factors relating physical, hydrological, and chemical features to capture fisheries yields in

Asia, Moreau and De Silva (1991) reviewed data on a large number of reservoirs and

Box 1 Factors affecting the fish yield of reservoirs

Factors increasing yield

Extent of shoreline development (coves, bays)

Existence and extent of marginal vegetation

Tree and brush clearing

Average depth of less than 18 meters

Conditions that permit passage of migratory fish

Introduction of species well adapted to lentic environment

Existence of permanent fisheries

Use of modern fishing gear

Enforcement of fishery regulations

Management and financial assistance to fisheries

Factors reducing yield

Erosion in reservoir watershed areas

Reduction of water flow into reservoir

Large seasonal fluctuations in water level

Fish species composition favoring predatory species

Pollution in reservoir watershed areas

Note: Based on reservoirs in Brazil.

Source: Paiva 1976.

lakes in the Philippines, Sri Lanka, and Thailand. They found that total capture fisheries yields and yields per unit of area in Asian reservoirs were related more to morphometric features (water area, catchment area, ratio of catchment area to water area, mean depth, shoreline development index) than to biological features. They argued that morphometric factors will be more effective than other factors in predicting fisheries yields in Asian reservoirs for several reasons: Unlike morphometric factors, biological factors vary significantly from year to year. Morphometric factors are easily measured for large numbers of water bodies. And morphometric factors are not influenced by cultural factors.

Soemarwoto and others (1990) characterized the Saguling and Cirata Reservoirs on the basis of 14 morphometric and hydrological variables. Assembling an Asia−wide database characterizing reservoirs according to such morphometric factors might be an effective approach for predicting capture fisheries yields from Asian reservoirs.

Reservoir Capture Fisheries

Sustaining Reservoir Capture Fisheries

The yields of reservoir capture fisheries are constrained by the priorities given to water use for human needs, as well as by a number of other environmental and social factors. One of the most important points to recognize with any capture fishery is that the aquatic ecosystem itself imposes limits on yields and that no amount of management and fisheries enhancement will increase the production of wild fish stocks beyond certain biological limits (Munro, Iskandar, and Costa−Pierce 1990). In a well−managed, shallow, tropical reservoir, capture fishery harvests normally do not exceed 50150 kilograms per hectare a year. Larger, deeper reservoirs can be expected to yield substantially less because much of the water and the benthic ecosystem lie in the deoxygenated hypolimnion below the thermocline.

Capture fisheries yields from Asian reservoirs are usually low, seldom more than 50 kilograms per hectare a year (Yap 1987). The exception in Asia is small, shallow reservoirs stocked with a prolific African fish, the Mozambique tilapia (*Oreochromis mossambicus).* Average capture fisheries yields of shallow Indonesian reservoirs with tilapia are 200400 kilograms per hectare a year (Hardjamulia and Suwignyo 1988). Similar reservoirs in Sri Lanka produce 283307 kilograms per hectare a year (De Silva 1988b). Deep reservoirs (more than 30 meters) yield much less even with repeated stocking of tilapia. For example, the 36.4−meter−deep Jatiluhur Reservoir in West Java produced average yields of just 1037 kilograms per hectare a year even with annual restocking of tilapia.

In efforts to enhance and sustain reservoir capture fisheries, the main technical issues to be considered are these:

Preservation and enhancement of natural stocks, including mitigation of physical barriers to breeding.

Selective fishing to control populations of predator fish.

Stocking and protection of stocked material (for example, protected nursery areas).

Creation of new spawning grounds or preservation of existing ones.

Regulation, participatory community management, and habitat preservation.

Mitigating Physical Barriers

There are few true anadromous fish (those that migrate to spawn in fresh water) in Southeast Asia. But elsewhere in Asia, and in Africa, Australia, and the United States, populations of anadromous fish have been decimated by dams and aqueducts. In India, Pakistan, and Sri Lanka the Indian shad (*Hilsa ilisha)*, mahaseer (*Tor khudree)*, and mountain labeo (*Labeo fischeri)* have virtually disappeared since the construction of reservoirs on a number of river systems.

To combat such losses in India, broodstock of major and minor Indian carp species are transported from the river to pens in the reservoir, where the fish breed at the onset of the monsoons

(Sreenivasan 1986). Unlike in Latin America and the former Soviet Union, however, there has been little work in Asia on fish passageways and ladders (Pavlov 1989; Quiros 1989).

Controlling Predators through Selective Fishing

In Asian reservoirs the guiding principle of fisheries management is to increase the production and yield of fish that feed at the lowest levels of the aquatic food web, mainly herbivorous and omnivorous fish. Predators, because they reduce the biomass of fish harvests, need to be controlled or fished out.

Exerting intensive, selective fishing pressure on predator fish has been a successful management tool in many Asian countries. The main predator fish of concern in Southeast Asian reservoirs are native carp (*Hampala macrolepidota),* catfish (*Clarias* spp., *Macrones* spp., *Mystus* spp., and *Wallago* spp.), and snakeheads (*Channa* spp.). Success in reducing predator fish populations has been notable in the Gandhi Sagar Reservoir in India and the Ubolratana Reservoir in Thailand (Bhukaswan 1980; Costa−Pierce and Soemarwoto 1990a). In Gandhi Sagar longline techniques are used for fishing predators. In Ubolratana longlines, gill nets, baited traps, cast nets, harpoons, and hooks and lines are used to catch predators, which have decreased both in size and in number. Forage fish such as native carp and pelagic sardines now dominate catches.

Introducing and Stocking Species

Stocking involves adding fish to a reservoir from hatcheries or other outside sources. Stocking is done for several purposes: to enhance the yield of a reservoir by altering the balance of species, to fill an ecological niche perceived to be vacant, to make up for a lack of natural reproduction, to replace fish that have died catastrophically, to provide food or sport, to control nuisance weeds, to provide food for desirable fish, and to provide employment (Bhukaswan 1980). Two types of stocking programs have been conducted in Asian reservoirs: one−time or occasional supplemental stocking of self−sustaining (naturally reproducing) species and repetitive restocking of nonreproducing (or occasionally reproducing) species. Fernando (1980) summarized a strategy for stocking fish in Asian reservoirs:

Give priority to managing indigenous species from riverine and wetland areas in the vicinity.

Do not automatically stock on an annual or seasonal basis in order to harvest stocked fish with resident fish. Most Southeast Asian reservoirs have resident populations of predators that can decimate the small stocks of introduced fish.

Never stock predator fish in countries where the availability of protein food—not sport fishing—is the overriding concern.

Promote the introduction of self−perpetuating species.

Develop cage aquaculture, especially in reservoirs dominated by predators.

Introduce pelagic and deep−water fish where the reservoir ecosystems and gear are appropriate.

Use large fingerlings for stocking and encourage selective fishing of predators before stocking in small reservoirs to increase fish yields.

Fish that are introduced can be either indigenous or exotic. Because of the increased concern about the environmental impact of introduced species in many Southeast Asian countries, Costa−Pierce and Soemarwoto (1990a) developed guidelines for introducing exotic species.

The stocking of self−reproducing fish species, especially of the tilapia, has been very successful in Indonesia, the Philippines, and Sri Lanka (Baluyut 1983; De Silva 1987 and 1988b; Sarnita 1987; Guerrero 1988; de los Trinos 1992; Hardjamulia and Suwignyo 1988). Repetitive restocking of fish to enhance or rehabilitate fish populations, however, is not always the best or most appropriate way to increase fish stocks and production. Indeed, from a cost−benefit perspective, many fish restocking programs are difficult to justify. But fisheries departments throughout the world are often compelled to conduct stocking programs because of pressure

from the public and politicians to "do something" to enhance the fish populations in unproductive lakes and reservoirs.

Creating Spawning Grounds

Spawning conditions for most reservoir fish species deteriorate over time because of shoreline degradation and fluctuations in water levels (Walburg 1976). To improve spawning conditions for desired species, existing knowledge on the place and timing of spawning and on environmental factors that trigger spawning can be combined with field observation to identify the areas, the seasons, and the biological factors that are key in the spawning of both desired and undesired species. Artificial spawning areas can be created in key sites to expand fish populations.

Protecting Fisheries through Regulation and Community Management

Even the most elaborate fisheries management and regulatory system will collapse unless measures are taken to protect fish populations. Although communities and governments can take such measures separately, protection will be impossible if both do not take action.

Fisheries regulations and controls fall into several common categories (Munro 1983):

Closed areas —bans on fishing in the main spawning grounds and in nursery areas for the most important species of a fishery.

Closed seasons —bans on fishing during the spawning and nursing periods of important species.

Gear regulations —bans or seasonal restrictions on the use of gear.

Size regulations —restrictions on keeping fish below a certain size or weight.

Limited entry —quotas on fishers and on the gear they can use and limits on time spent fishing.

Prohibitions —bans on use of fishing gear and methods that cause indiscriminate damage to stocks, such as seines, trawls, poisons, and explosives.

It is questionable whether such regulations can be enforced in many tropical nations, however, because of lack of financial resources and of people with appropriate training, among other socioeconomic problems.

Successful Models of Reservoir Capture Fisheries

Successful reservoir capture fisheries in Southeast Asia range from self−sustainable, non−restocking enterprises to "put and take," or regularly restocked, intensively managed capture fisheries. Three notable examples of successful capture fisheries using an ecosystems management concept are tilapia in Indonesia and in Sri Lanka and freshwater sardines in Thailand.[3] Reservoir capture fisheries in all three countries produce fish at a competitive price for local consumption. These important models illustrate the diversity of sustainable paths that may be taken to develop fisheries in small to medium−size reservoirs.

Capture Fisheries Integrated with Other Reservoir Uses through Zonation in Indonesia

Suwignyo (1974) attributes the success of Indonesian reservoir capture fisheries to the development of a self−sustaining concept—achieving a balance between the carrying capacity of the water body and fishing pressure through zonation. Indonesian scientists and government officials contributed to the design of a zonation system that has allowed development of productive capture fisheries in four reservoirs of the Brantas River basin in East Java: Selorejo, Karangkates, Lahor, and Wlingi. The four reservoirs, the subject of collaborative studies by Institut Pertanian Bogor (Bogor Agricultural University), BIOTROP (Bogor), and the Indonesian Department of Public Works, serve as test beds for institutional and planning mechanisms that may help to sustain capture fisheries in small tropical reservoirs.

The Indonesian reservoirs are multipurpose reservoirs for electricity generation, drinking water supply, irrigation, and flood control. To ensure that fisheries do not hamper these functions in any way, a zonation pattern was developed for the reservoirs

that delineated four fisheries zones: a prohibited zone, a conservation zone, a regulated zone, and an open, or unregulated, zone.

The prohibited zone is the area closest to the dam and is closed to fishing for security and safety reasons. It includes the area around the dam and installations connected with dam functions, and dangerous areas near the outflow. The conservation zone is also closed to fishing. It contains fish spawning and nursery grounds, including river mouths and nesting sites. In the regulated zone capture or culture (aquaculture) fisheries are allowed but regulated by limits on catch, size, or gear or by closed seasons. The open zone, where there are no regulations on fishing, exists only in large reservoirs in Indonesia.

The location and size of the zones are not fixed and may differ in every reservoir. And a reservoir may not have all the zones. The number and size of the zones in a reservoir are related to its size and morphometry. Figure 6 shows the delineation of fisheries zones in the Selorejo (400 hectares), Karangkates (1,500 hectares), and Lahor (260 hectares) Reservoirs.

In the Selorejo Reservoir the prohibited zone (zone 1) includes the area along the dam wall, the intake area delineated by the trash boom, and the spillway. The conservation zone (zone 2) comprises the areas where the Konto, Kwayangan, and Ngantang Rivers enter the reservoir. All other open−water areas are in the regulated zone (zone 3). Selorejo does not have an open zone because it is a small reservoir with heavy fishing pressure. It was estimated that 113 people fish the reservoir every day, with a fishing pressure of 751 person−hours a day (Hermanto 1978).

Although government fisheries agencies have stocked a number of species in Selorejo, fisheries have been dominated since the reservoir's impoundment by a wild, nonnative fish that was not stocked, the Mozambique tilapia (*Oreochromis mossambicus).* Tilapia comprise about 70 percent of the hook and line catch and more than 80 percent of fish captured by nets.

Yields are high for capture fisheries in the small reservoirs, totaling 120140 tons, or 300350 kilograms per hectare, a year (Suwignyo 1974). Fishing in the four reservoirs is regulated through restrictions on the mesh size of gear. The mesh size must exceed 6 centimeters, which was found to be the size of tilapia after first spawning.

Initially the main concern of reservoir engineers was to ensure that the water was "clean" and that fisheries did not conflict with the main purpose of the reservoirs—water storage. The managers succeeded in achieving at least the second goal: capture fisheries developed after dam construction in a manner that ensured that there would be no conflict with the primary activities of irrigation and power generation.

Capture Fisheries for Freshwater Sardines in Thailand

In Thailand indigenous species have been developed in reservoirs ranging in size from 1,200 to 4,100 hectares. Yields are low, averaging 47 kilograms per hectare a year (Chookajorn and Bhukaswan 1988). In some years, however, gross returns from reservoir fisheries have exceeded the revenue from electricity. For example, the 41,000−hectare Ubolratana Reservoir in north−east Thailand produced fish worth 40 million baht in 1978, while electricity sales generated just 30 million baht (Costa−Pierce and Soemarwoto 1990a).

The main fish in the Ubolratana Reservoir is a small freshwater sardine (*Cludeidichthys aesarnensis)* that occupies the pelagic areas of the reservoir (Sirmongkonthaworn and Fernando 1994). The sardine is fished with simple technology (light traps and nets) and used as a low−cost food or rendered into fish sauce for export to Bangkok (Costa−Pierce and Soemarwoto 1990a). The sardine represents a solution to one of the most intractable technical problems in large tropical reservoirs: finding a suitable species to inhabit the large, nearly devoid open−water fisheries zone found in the great majority of these reservoirs (Fernando and Holcik 1982).

An interesting feature of the sardine fishery is its social setting. Out−migrations from northeast Thailand to Bangkok due to a lack of rural employ−

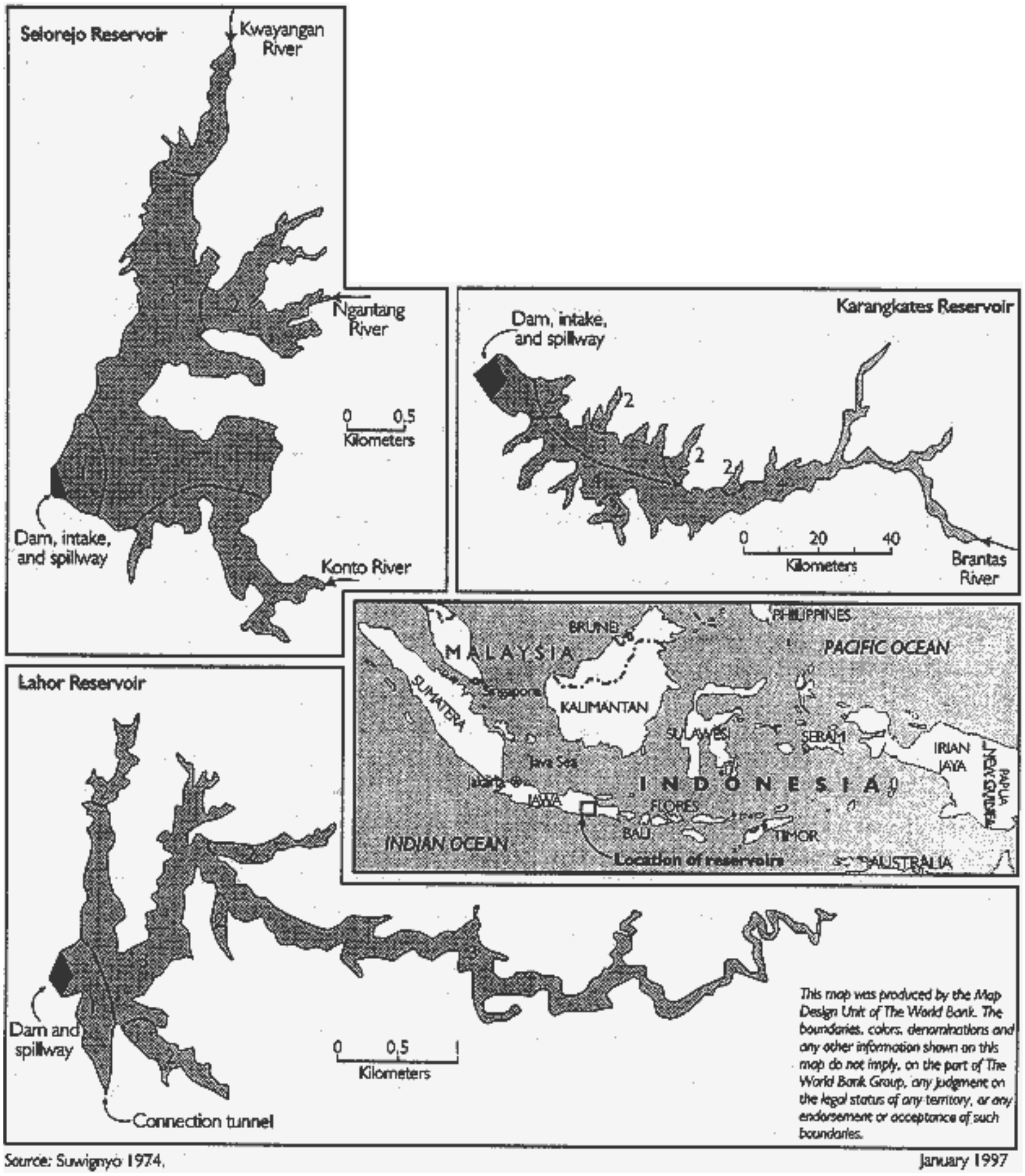

Figure 6
Zonation has helped sustain capture fisheries in Indonesian reservoirs
1 Prohibited zone
2 Conservation zone
3 Regualted zone
4 Unregualted zone

Source: Suwignyo 1974.

ment opportunities had taken their toll. But because of the development of the pelagic sardine fishery, fishing families now migrate seasonally between the Gulf of Thailand and the Ubolratana Reservoir in the northeast.

Capture Fisheries for Tilapia in Sri Lanka

Sri Lanka has an estimated 175,000 hectares of reservoirs (Fernando and De Silva 1984), expected to increase to 250,000 hectares by 2000 (De Silva

1992a). Relative to land area, Sri Lanka has a greater area of freshwater reservoirs than any other nation, estimated at 3 hectares of reservoir surface per square kilometer of land and expected to increase to 4 hectares by 2000 (De Silva 1983). The capture fisheries in these reservoirs, among the most studied in the world, are dominated by catches of an imported, exotic species, the Mozambique tilapia (*Oreochromis mossambicus)* (De Silva 1988b). Inland reservoir fisheries in Sri Lanka yield 27,00030,000 tons a year for an average fish production of 283307 kilograms per hectare a year (De Silva 1988b).

Fish yields from the commercial fishery have been shown to be positively related to fluctuations in the water levels of the reservoirs. In the Parakrama Samudra Reservoir fish yields were significantly related to the mean water levels in the previous three years (De Silva 1986).

Despite the success of the Sri Lankan reservoir fisheries, their management cannot serve as a model for sustainable aquatic ecosystems management. The fisheries involve little coordination between communities and government and have not been developed on a scientific basis. According to De Silva (1988b),

Basic questions as to when to commence fishing and what the initial fishing pressure should be in newly impounded reservoirs are being solved or attempted to be solved through intuition rather than scientific reasoning. (p. 25)

The only regulations imposed on the reservoir fisheries has been a minimum mesh size of 50 millimeters and a prohibition on the use of seines. In addition, fishermen's cooperatives sometimes agree to cease fishing during dry years for brief periods (two to three months) every two to three years when yields decline. The effects of these measures are not known (De Silva 1988b).

Reservoir Culture Fisheries

Culture fisheries, or aquaculture, can dramatically increase fish yields in reservoirs. Depending on the river basin's fertility and on technical, socioeconomic, and marketing considerations, a wide variety of aquaculture systems can be developed that are vastly more productive than capture fisheries.

For a reservoir aquaculture development project to succeed, however, adequate consideration must be given at the planning stage to sociocultural, infrastructural, economic, marketing, and other vital factors.

Sociocultural factors. It is essential to assess the acceptability of fish as food among consumers, to estimate the fish consumption rate of the target group, and to determine the product form and sizes preferred by the group. For religious or other reasons, some cultures are primarily vegetarian or prefer protein from other animal sources.

Economic and marketing factors. Planners should assess the market and price competition from alternative terrestrial and aquatic protein sources, especially from lower−cost fish caught seasonally (or year−round) in wild fisheries. They should also estimate the capital and operating expenses of producers and the resulting cost of fish to the consumer.

Infrastructure. The condition of a country's basic infrastructure—roads, communications, marketing (refrigeration), airports—might present constraints to aquaculture development.

Environment. Suitable sites must be available, water quality should be good and temperatures appropriate, and there should be no chemical or pesticide pollution or fish diseases.

Technical factors. There should be adequate supplies of fish seed and feeds and aquaculture equipment.

Availability of trained managers. Expertise in aquaculture management is essential. Trained personnel understand the fundamentals of aquaculture production systems: stocking, feeding, disease prevention and treatment, and harvesting and marketing.

Political stability. Aquaculture has acquired a reputation in some areas as a high−risk venture. If political risks are added, an aquaculture project is doomed.

Traditional knowledge of fisheries. In many parts of Asia there are "fisheries cultures" that have traditional knowledge of aquaculture and fisheries systems handed down through the generations. In many of these societies farmers are as expert as scientists. But other cultures have little experience with "water farming."

Laws and regulations. Taxes, permits, import duties, and regulations on sales, species, and drugs can determine the success or failure of aquaculture.

Aquaculture Systems

There are two general types of reservoir aquaculture systems, water−based and land−based. The main advantages of water−based aquaculture systems are that they do not take up scarce land and they intensify the productive use of the lake water surface, an underexploited resource. The primary water−based aquaculture systems are cage culture and pen culture.

Land−based aquaculture systems are capital intensive. They require facilities for holding and

raising fish—ponds, tanks, silos, or concrete basins (raceways)—and infrastructure for water supply and flows. Developed to serve as hatcheries and nurseries in support of cage and pen systems in reservoirs, however, land−based aquaculture systems can play a vital part in the long−term sustainability of new, water−based (reservoir) aquaculture systems.

Cage Culture

In cage culture fish are raised in circular, square, or rectangular net bags suspended in the water, either floating from a raft (offshore cage culture) or fixed to the bottom near the shore in the littoral zone. In nearshore cage culture the four sides of the net bag are attached to stakes driven into the reservoir bottom. Floating cage culture is more suitable for reservoirs subject to large fluctuations in water level.

Cage culture can be practiced intensively, semiintensively, or extensively. The intensity of operations depends mainly on the economics—the availability of fingerlings and feed and the market demand for fish products.

Cages can be used as hatcheries, nurseries, or grow−out systems, depending on the development of the aquaculture production network (see section below on such networks). Multispecies stocking has been carried out where species are compatible with each other or where a "janitor" fish is stocked at low density to prevent algae from clogging nets or to clean parasites off a commercial species.

Hatchery and nursery systems. Technical problems remain to be solved in order to make the entire operations for the cage culture of many fish species in reservoirs fully floating. Common carp, one of the most important food fish, is one example. The spawning of common carp in cages in reservoirs has been successful in India using water hyacinths as substrates for egg collection (Tripathi 1987). For an acceptable survival rate after hatching, however, common carp require zooplankton feed of an increasing size until they reach about 4050 grams, when they readily accept feeds with lower protein content. The remaining technical problem is the need for a technique that would enable common carp to be raised from hatching to 4050 grams in floating net cages. Experiments to date have proved unsuccessful or uneconomic compared with land−based hatchery and nursery methods (Costa−Pierce and Hadikusumah 1990).

Floating hatcheries and nurseries for tilapia, however, are well developed, making rapid expansion of the cage culture of this species in tropical reservoirs possible. The water−based hatchery and nursery technologies for tilapia are well known and are economically competitive with land−based methods (see Beveridge 1987, Behrends and Lee 1990, and Costa−Pierce and Hadikusumah 1995 for discussion of the techniques and economics).

Single cage systems. In the Saguling and Cirata Reservoirs commercial cage aquaculture is conducted in net bags (7 ≥ 7 ≥ 2.5 meters) floated from a raft of bamboo and oil drums. The cages are stocked with approximately 300 kilograms of common carp fingerlings averaging 50100 grams. Three to four months later, 1.01.5 tons of fish of 300500 grams can be harvested (table 2).

Table 2 Yield characteristics of common carp (*Cyprinus carpio)* in floating net cages

	Stocking			*Harvest*						
Cage	*Total volume (kilograms)*	*Average weight (grams)*	*Number of fish*	*Total volume (kilograms)*	*Average weight (grams)*	*Number of fish*	*Length of cycle (days)*	*Survival rate (percent)*	*Feed (kilograms)*	*Food conve ratio a*
1	300	71.6	4,190	905	217.4	4,162	90	99	1,328.2	2.2
2	300	68.1	4,407	1,225	283.8	4,316	82	98	1,536.5	1.7
3	300	68.2	4,397	982	241.8	4,062	90	92	1,441.9	2.1
4	300	74.8	4,009	1,168	293.6	3,978	89	99	1,677.8	1.9

a. Food conversion ratio is the dry weight of feed in kilograms divided by the wet weight of fish in kilograms.

Note: The cages (7 ≥ 7 ≥ 2.5 meters) were stocked at 2.4 kilograms per cubic meter (300 kilograms per cage) and fed at 3 percent body weight per day with a commercial feed of 2426 percent crude protein. Stocking and management followed th practices used by the majority of farmers in the cage culture industry documented in Bongas, Saguling Reservoir.

Source: Costa−Pierce and Hadikusumah 1990.

Rusydi and Lampe (1990) estimated that a farmer operating three cages would have a net operating income of $500 per fish crop. With the possibility of three crops a year if sufficient fingerlings and feed are available, the income potential for the single cages is excellent. As a result, this type of cage aquaculture has expanded rapidly in the Saguling and Cirata Reservoirs in Indonesia.

Biculture cage systems. Costa−Pierce and Hadikusumah (1990) demonstrated the feasibility of a biculture cage system in which common carp were raised in small−mesh cages floated above or placed within larger cages used for raising tilapia. Common carp fingerlings in two cages (2.4 ≥ 4.0 ≥ 1.2 meters) with net mesh of 23 millimeters were placed in a single outer net (7 ≥ 7 ≥ 2.5 meters) with 4−centimeter mesh. The outer nets were stocked with two sizes of tilapia, with mean weights of 84 grams and 208 grams. Feed was given at a rate typical for common carp nursery culture, while a maintenance ration was fed to the tilapia. Common carp in nurseries within the tilapia cages had significantly higher net production, higher mean weight at harvest, and lower food conversion ratios (FCRs, the ratio of the dry weight of feed to the wet weight of fish produced, in kilograms) than carp in nets with no tilapia on the outside. It was hypothesized that the low FCRs were due to increased food availability, which occurred because the tilapia kept the nets free of attached organisms. In addition, a second crop of fish was produced from the same feed inputs, since the tilapia were eating these organisms and recycled feed and fish waste from the carp nets above them.

By 1993 at the Saguling Reservoir, cage farmers in the Bongas area were observed practicing an important new commercial variation of this biculture cage system, reflecting the innovativeness of farmers and the presence and evolution of traditional knowledge systems in the new reservoir aquaculture industry. The production of tilapia in cage aquaculture had grown substantially in the Bongas cage culture industry, from zero in 1989 to an estimated 15 tons a day in 1993. By that year five fish transport vehicles were carrying 3 tons each of freshly harvested tilapia each day from Saguling to Jakarta.

Nearly all the tilapia were produced in biculture cage operations in which common carp were raised in inner cages and tilapia in outer cages. The inner cages were 7 ≥ 7 ≥ 7 ≥ 3 meters with 1.5−centimeter mesh. The outer nets were also 7 ≥ 7 meters, but had a total depth of 3.54.0 meters, so that the tilapia had a space 50100 centimeters in depth below the carp cage.

Farmers' stocking and harvest cycles were structured around the facts that common carp were reported to grow faster than tilapia and that market preferences in Jakarta were for tilapia of 200300 grams. Tilapia were stocked at an average weight of about 25 grams in outer nets, and common carp, averaging about 50 grams, were stocked in inner nets. The total stocking weight was 300 kilograms of common carp and 150 kilograms of tilapia. Feed was given only to the common carp. The feed (2425 percent protein) was given three to five times a day at 30 kilograms per cage per day, for a total of 2.53.0 tons over a common carp grow−out period of two and a half to three months. At the end of the period common carp were harvested at an average weight of about 330 grams.

The tilapia remained in the outer net while another common carp grow−out cycle was initiated. After another two and a half to three months the second batch of common carp was harvested at a size similar to that of the first cycle, and then the tilapia were harvested. After the total of six months the tilapia averaged about 250 grams.

In one year four crops of common carp and two crops of tilapia were taken. Assuming conservative survival rates of 90 percent for common carp and 95 percent for the tilapia, each three−month carp cycle produced about 1.8 tons, and each six−month tilapia cycle 1.4 tons. If enough fingerlings were available, 10 tons of fish could be harvested for every 49 square meters of water surface using this method, or 204 kilograms per square meter per year. This production rate is among the highest recorded for any animal protein production system.

Subsistence cage and mini−cage systems. Costa−Pierce and Hadikusumah (1990) estimated the capital costs for the 7 ≥ 7 ≥ 2.5 meter commercial cages in

the Saguling Reservoir in 1989 at Rp 491,200 (in 1989 US$1 = Rp 1,796). They developed improved construction methods that reduced capital costs to Rp 274,500. They also engineered a cage system that did not require expensive oil drums for flotation but instead used bamboo, for a total capital cost of Rp 177,500.

Shortly after inundation 64 percent of the people displaced by the Saguling and Girata Reservoirs remained below the Indonesian poverty line (Suwartapradja and Achmad 1990). Thus, the majority of displaced people lacked the capital to invest in even the lower−cost commercial cage models. As a result, the development of intensive mini−cage and subsistence cage systems was undertaken (CostaPierce and Hadikusumah 1990; Schmittou 1992).

The capital costs for constructing a 17−cubicmeter subsistence bamboo cage were Rp 60,000. Fish production in such cages ranged from 136 to 153 kilograms over periods of 8690 days. It was calculated that, with proper management over successive 90−day grow−out cycles, two bamboo cages could provide an Indonesian family three fish of about 250 grams every day. The cages were durable, lasting more than two years in the reservoir (six cycles, three per year in 198789) with minor repairs.

Low−cost, one−cubic−meter mini−cage models were developed in Indonesia by Schmittou (1992). The total capital costs of such a cage were estimated at Rp 40,000, and the common carp production achieved was 200 kilograms per cage every three months. The net income per cage (with interest) was estimated at Rp 112,000.

These cage aquaculture models have tremendous potential to attract poor villagers with little capital into cage aquaculture. The mini−cage models could also serve as economic and biotechnical precursors to larger business ventures by small farmers. At the Saguling Reservoir many who owned small cages eventually saved enough of their earnings to become commercial cage owners.

Extensive cage culture of Chinese carp and tilapia. Prospective sites for cage culture are normally considered for their potential to sustain intensive culture in which formulated feeds are given to fish stocked at high densities (for tilapia, 412 kilograms per cubic meter, and for carp, 16 kilograms). Prospects for low−cost, extensive (no−feed) cage culture of carp and tilapia are often overlooked or underestimated. In extensive cage culture microphagous (small−particle−feeding) fish are raised at low stocking densities and are provided no feed or fed agroindustrial wastes, such as rice or maize bran, which has a low protein content (less than 10 percent) and is inexpensive.

Extensive cage culture of herbivorous or omnivorous fish at low stocking densities (tilapia at 0.020.69 kilogram per cubic meter and Chinese carp at 0.120.55 kilogram) in naturally or artificially enriched water bodies (mesotrophic to eutrophic) is a viable option for producing low−cost food fish. The Chinese silver and bighead carp (*Hypophthalmichthys molitrix* and *Aristichthys nobilis)* and tilapia (principally *Oreochromis niloticus)* are the fish most commonly raised in extensive cage culture in Asia, principally in cages in reservoirs in China, Nepal, and Singapore (Chookajorn 1982; Coche 1982; Hai and Zwieg 1987). Net production in nofeed cage culture for tilapia (*Oreochromis niloticus* and *O. mossambicus)* ranges from 0.3 to 7.5 kilograms per cubic meter, and for the Chinese silver and bighead carp from 0.6 to 2.8 kilograms. Fish culture periods range from 72 to 180 days for tilapia and 72 to 420 days for Chinese carp.

Successful extensive cage aquaculture requires that cages be sited in rich water bodies where concentrations of plankton and detrital and suspended organic matter are adequate to support fish that are confined to small spaces and have nonspecific, filter−feeding habits. Eutrophic and hypereutrophic water bodies are therefore excellent locations.

Pen Culture

A pen culture system consists of an enclosed area of shallow water, usually a cove, backwater, or bay sheltered from strong winds. Netting is attached to stakes (wood, bamboo, or metal) driven into the reservoir bottom. Pens require a flat reservoir bottom or one that slopes toward the main part of the reservoir and fairly stable water levels.

Most fish pens are operated as semi−intensive aquaculture systems: they are fed, fertilized, cleaned, and harvested regularly. In a well−developed aquaculture production network, pens can serve multiple purposes. They can be used to raise fish to market size. They can also be used to supply fingerlings to other aquaculture systems in the reservoir or to systems outside the reservoir. And, if operated as a hatchery, they can be used to conserve and enhance reservoir capture fisheries populations. Seeded with large broodstock, pens produce small fish (recruits) that can "leak out" through the meshes and colonize the reservoir, enhancing capture fisheries.

Pen systems are successful only where there are no large fluctuations in water levels such as those that occur in reservoirs associated with hydropower dams. For example, as a result of the routine 1520−meter drops in water level in the Saguling Reservoir, leading to an unacceptably high risk of crop losses, pen systems did not develop there, even though they were demonstrated to farmers. To avoid fish kills due to rapid drawdowns, additional canals and a sump pond were dug into the bottom of pens near the fence. As water drained from the pen, fish were directed by the canals into a sump pond. Nevertheless, after the first few years rapid drawdowns led to the stranding and loss of fish, and farmers moved to other, less risky aquaculture systems.

Aquaculture Production Networks

An aquaculture production network comprises the inputs, supplies, and markets that sustain an aquaculture system. Such networks range from isolated, undeveloped networks to segmented, integrated, and highly developed systems. Well−developed, segmented aquaculture industries have distinct hatchery, nursery, and grow−out sectors, with markets for farm−raised fish of all sizes. In the most underdeveloped networks single farmers (or farm families) must invest in and manage their own hatchery, nursery, and grow−out systems and raise fish of all sizes, though marketing only large fish (food fish). Indonesia, the Philippines, and Thailand have highly segmented aquaculture industries and welldeveloped markets for fingerlings and market−size fish.

A fully developed aquaculture production network is important not only because of the efficiencies it generates, but also because of the important social and economic benefits that it produces. The development of such a network is an evolutionary process—even in Asia, where aquaculture is most advanced. The network grows and changes shape as new production systems and market linkages arise to meet new demands. This process is illustrated by the evolution of an aquaculture production network for common carp in the Bandung regency of West Java.

In West Java the traditional aquaculture production network for common carp, dating to about 1910, linked pond hatchery systems to rice−fish nursery systems and family ponds for grow−out (figure 7). While urban markets provided a demand for large fish (0.5 kilogram or more), the demand in traditional markets in the rice−growing regions was for fish of just 50200 grams. Most of the fish from rice fields was sold in local markets for local consumption, but family ponds also produced large fish for sale in the cities (Costa−Pierce 1992d).

By 1976 the technical and economic feasibility of intensive culture of common carp in concrete raceway systems had been demonstrated. These systems proved profitable, and by 1985 more than 5,000 running water systems were operating. Fish markets expanded with the increased demand from a rapidly growing population. At the same time, running water systems created increased demand for fingerlings of 80−100 grams. This demand was not matched by an expansion in the rice−fish nursery systems, however, and fingerling shortages and price increases occurred.

During the late 1970s and 1980s pesticide use on rice skyrocketed in Indonesia, which at that time purchased about 20 percent of the world's rice insecticide. By the early 1980s traditional practices of fish culture in rice fields nearly disappeared. The small fish traditionally marketed in the rice−growing areas became scarce, and rural people were deprived of a vitally important, low−cost, traditional source of protein.

By 1986 the popularity of running water systems was on the decline as a result of management failures, rising feed and fingerling prices, and declining fish prices. In addition, the higher profitability and lower capital costs of floating cages in reservoirs had been successfully demonstrated. Owners of reservoir cages began to undercut owners of running water systems, exacerbating their financial problems. Dramatic changes occurred in the aquaculture production network.

Fish markets expanded with continued population growth, but the number of registered running water systems fell by more than 50 percent. Cage aquaculture grew dramatically in the Saguling Reservoir from 1986 to 1990 and in the Cirata Reservoir after 1989 (Sutandar and others 1990), leading to substantial new fish production from the two reservoirs, estimated at 10,000 tons a year by the end of 1992.

During this period Indonesia's rice sector had two massive outbreaks of brown plant hopper pests, and the resistance of rice pests to a number of commonly applied broad−spectrum pesticides increased significantly. As a result, a 1986 presidential decree banned the use of 57 broad−spectrum pesticides on rice. These events in the rice sector, combined with

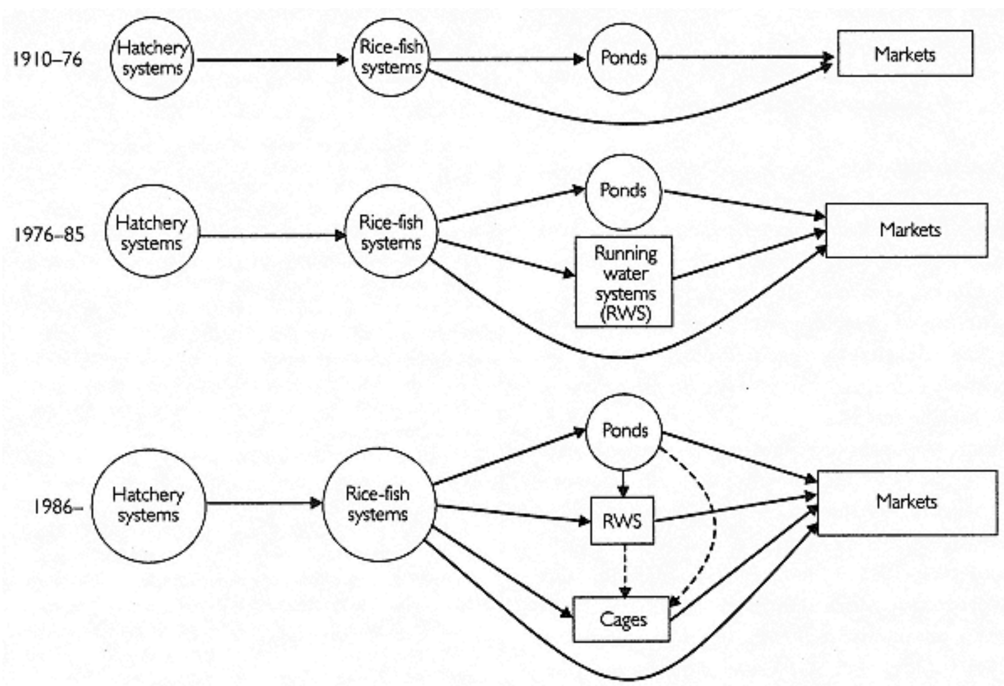

Figure 7
An aquaculture production network is a dynamic system

The figure shows the historical development of the aduaculture production network for common carp in West Java,Indonesia. Between 1910 and 1976 a traditional network developed in which rice−fish systems supplied seed fish for grow−out in and fish for local consumers in the rice−growing districts. Between 1976 and 1985 fish markets grew as a result of the rapid population growth in West Java, and ponds and rice−fish systems increased in number. Running water systems were introduced, increasing the demand for seed fish and contributing to the growth in rice−fish pond nurseries. The production of small fish for local markets declined. The year 1986 marked the beginning of a period of continuing change. Demand for freshwater fish continued to grow, but the number of traditional fish ponds remained relatively constant because of urbanization, and the number of running water systems dropped sharply. The rapid development of reservoir cage culture created new demand for seed fish, boosting the growth of rice−fish nurseries, which still supplied a small amount of fish to local consumers. How will the network evolve? The dashed lines indicate possible future directions of development

Source: Costa−Pierce 1992d.

the increased demand for seed fish for stocking cage grow−out systems, led to a sharp increase in the area devoted to rice−fish culture in West Java and to an expansion of pond hatcheries (Costa−Pierce 1992d).

Many of the changes in West Java's aquaculture production network have proceeded with little planning, occurring largely as a result of shifting market forces. The planning to develop cage aquaculture in the Saguling and Cirata Reservoirs in connection with the resettlement, in particular, gave little attention to the tremendous potential boost to overall regional development that the carefully planned development of a sophisticated aquaculture production network can provide. Even so, the reservoir aquaculture development probably created far more indirect employment—jobs and new business opportunities—in hatcheries, nurseries, and rice−fish culture than direct employment in the reservoir aquaculture industries.

Carrying Capacity

There is a limit to the number of aquaculture units that a body of water can support before selfpollution or negative feedback occurs, reducing the productivity of aquaculture activities. This limit—or carrying capacity—is reached more quickly by intensively managed units receiving large amounts of high−protein feed.

Some work has been done to measure the effects of different types of semi−intensive and intensive cage culture on the water quality of reservoirs (Beveridge 1984; Costa−Pierce and Roem 1990). Costa−Pierce (1992b) found that the environmental impact of cage culture in the Saguling Reservoir was insignificant compared with the impact of the 150,000 cubic meters of raw sewage discharged into the reservoir each day, the impact of turnovers that bring nutrients previously locked in the bottom waters to the surface, and the impact of routine fluctuations in water level (box 2).

Much less work has been done on the larger question of the limits that self−pollution by cages puts on the number of cages per unit of surface area or water volume. Most guidelines are arbitrary. In Chinese reservoirs, for example, the recommended ratio of cage area to reservoir area is 1 to 500 (Lin, Guggenheim, and Costa−Pierce forthcoming). After measuring the biological oxygen demand (BOD) of concentrated fish wastes settling from carp cage culture in the Saguling Reservoir, the Institute of Ecology (IOE) and the International Center for Living Aquatic Resources Management (ICLARM) recommended that cage aquaculture in that reservoir be limited to four 7x7 meter cages per hectare, or 22,640 cages, a 1 to 50 ratio (IOE and ICLARM 1989).

The carrying capacity of cages in a reservoir will be higher with higher throughput or water exchange rates, as in a hydropower reservoir. Although there are no reports available indicating that reservoirs with high water exchange rates could support a higher number of intensive cage units, the IOE and ICLARM (1989) proposed this as a reasonable assumption.

Box 2 Combined uses of reservoirs

In many developing countries the primary or secondary use of reservoirs is as a supply of potable water. In theory there are no conflicts between fisheries and community water supplies, since water suitable for drinking is excellent for fish production and vice versa. In Singapore bighead carp (*Aristichthys nobilis)* are kept in cages as biological control agents in drinking water reservoirs (Chookajorn 1982). The fish, which receive neither feed nor fertilizer, are used solely to control noxious algal blooms that contribute to taste and odor problems.

But excessive aquaculture development can have detrimental effects on the quality of reservoir and lake water. Although there have been few studies of this issue in the Tropics, Beveridge and Phillips (1993) have theorized that cage aquaculture that exceeds the absorptive capacity of its aquatic ecosystem will lead to noxious algal blooms and weed problems, degrading water quality. In India, however, nearly all reservoirs are used for both drinking water and fisheries, even when their main purposes are irrigation and hydropower. For example, in the Poondi Reservoir in Tamil Nadu, a drinking water reservoir, productive capture fisheries have been developed with no detrimental effect on water quality; in fact, the reservoir's water quality is well within World Health Organization (WHO) standards (Sounder, Franklin, and Sreenivasan 1971; Sreenivasan 1977). The development of fisheries in drinking water reservoirs is not permitted everywhere, however, and is banned in China, for example.

Site Selection for Cage Aquaculture

The site selected for cage aquaculture is an important determinant of business success or failure. The main criteria for site selection are technical and social. For a producer, the best site is one in which the chosen species will reach optimum market size in the shortest possible time and can be readily sold at a high price in an open market. Technical factors to consider in site selection include these:

Exposure. A site should be sheltered from strong winds, storms, and damaging waves yet have relatively constant winds and waves to provide regular flushing. Interviews with local residents can help in identifying storm patterns, unusual weather, and the directions of seasonal winds. Sites surrounded by land whose topography will channel storm winds and waves should be avoided.

Flushing. Relatively sheltered bays connected to a river, a tributary, or an inlet that ensures good flushing rates (high water renewal rates) are excellent sites for cage aquaculture. Sites in hydropower reservoirs with high water exchange rates are preferred.

Basin morphometry. In a reservoir subject to turnover events the shape of the bottom can either prevent or facilitate the rapid movement of deoxygenated bottom water to the surface. In the Saguling Reservoir, which experiences annual turnover events, cages in bays protected from the wind and with V−shaped bottoms were unaffected by turnovers, but cages in unprotected bays with U−shaped (or plate−shaped) bottoms all experienced catastrophic fish kills.

Water quality. For semi−intensive and intensive cage culture, sites in which there have been fish kills due to turnover events, that are subject to landslides during heavy rains, or that receive organic, chemical, or industrial discharges should be avoided. In choosing a site, temperature, oxygen, and pH should be measured two to three times a week during the onset of the rainy season (for four to eight weeks) at 4:00 to 6:00 a.m. to determine the suitability of the site during this most critical period.

The social factors to consider in site selection include the following:

Marketing. Marketing costs should be kept as low as possible. In this regard, the best site is one to which buyers can easily come to make direct purchases and where there is good infrastructure for transporting products from the site.

Vandalism and theft. Sites should be located in areas that can be easily guarded and are free from social unrest.

Political and legal factors. Sites should be acceptable to local and other authorities and involve minimal legal or regulatory complexity and associated costs.

Costs and availability of services. Sites should be in areas where capital and operating costs and services will allow profitability and where there is traditional knowledge of complex agricultural systems and knowledge of hydrobiological and irrigation systems.

Cultural and aesthetic acceptability. Sites for cage aquaculture systems should be culturally and aesthetically acceptable to the community. Ensuring that a system fits into the local environment and is a source of community pride is preferable to continually battling special interest groups.

An Ecosystems Approach to Planning Reservoir Fisheries

Integrated fisheries ecosystems can be adapted to a wide range of environmental and social conditions. A pictorial representation of an integrated system incorporating fisheries and aquaculture, drawdown agroforestry, aquaculture production networks, and land−based markets illustrates the range of possibilities for new productive enterprise that can be developed to revitalize a society and its economic and ecological systems (figure 8). The system depicted in the figure is modeled on a development plan for fisheries ecosystems in the Saguling−Cirata hydropower reservoirs in West Java, Indonesia.

There are few models of reservoir ecosystems that have been designed in this way—as interactive land−water ecosystems with the aim of increasing the social and economic benefits. Nor has any planning system been devised for developing reservoir fisheries and aquaculture as part of a fully developed aquaculture production network or an overall regional development plan.

An ecosystems management approach provides the basis for planning the integrated development of reservoir fisheries and aquaculture. Sustainable fisheries require inputs from outside the reservoir system (seed fish, feed, capital), which in turn produce outputs that are of value outside the system or as inputs for the system itself. Numerous recycling pathways are evident in such a system. Depending on local conditions, more pathways can be designed to enhance the productivity and sustainability of the new, evolving, productive enterprise systems. An ecosystems approach to planning can help fisheries benefit from the recycling pathways and can develop complementary economic uses of the reservoir and basin area.

Organic Pollution as a Misplaced Resource

In Asia hydropower and irrigation reservoirs increasingly are being located near the urban areas they serve in order to reduce the costs of power and water transmission. Because most Southeast Asian nations lack adequate means of sewage disposal, storage reservoirs near major urban areas generally receive large loads of untreated sewage.

For most Asian nations, diverting this sewage stream into centralized sewage treatment facilities is not a solution they will be able to afford at any time in the near future (Edwards 1992). If the sewage stream is untainted by heavy industrial or chemical pollution, an alternative solution is to divert the diluted sewage stream into simple oxidation ponds for fish culture, as has been successfully done in Calcutta, India (Edwards and Pullin 1990). More than 24,000 people are employed in Calcutta's sewage−fed fisheries, which send about 20 tons of fish a day to the city's markets, 1020 percent of the fish consumed by the residents (Gosh 1990).

Organic pollution from runoff, nutrients, and sewage was also a problem in the Saguling Reservoir in Indonesia. As the Citarum River coursed through the city of Bandung, it picked up a large organic nutrient load and water hyacinths. The river, dammed downstream by the Saguling hydropower dam, delivered the nutrients and weeds to the northeastern sector of the reservoir.

Water hyacinths developed rapidly in the reservoir. Alarmed, the Indonesian State Electric Company (PLN) undertook regular mechanical removal of the weeds and erected a weed boom, or

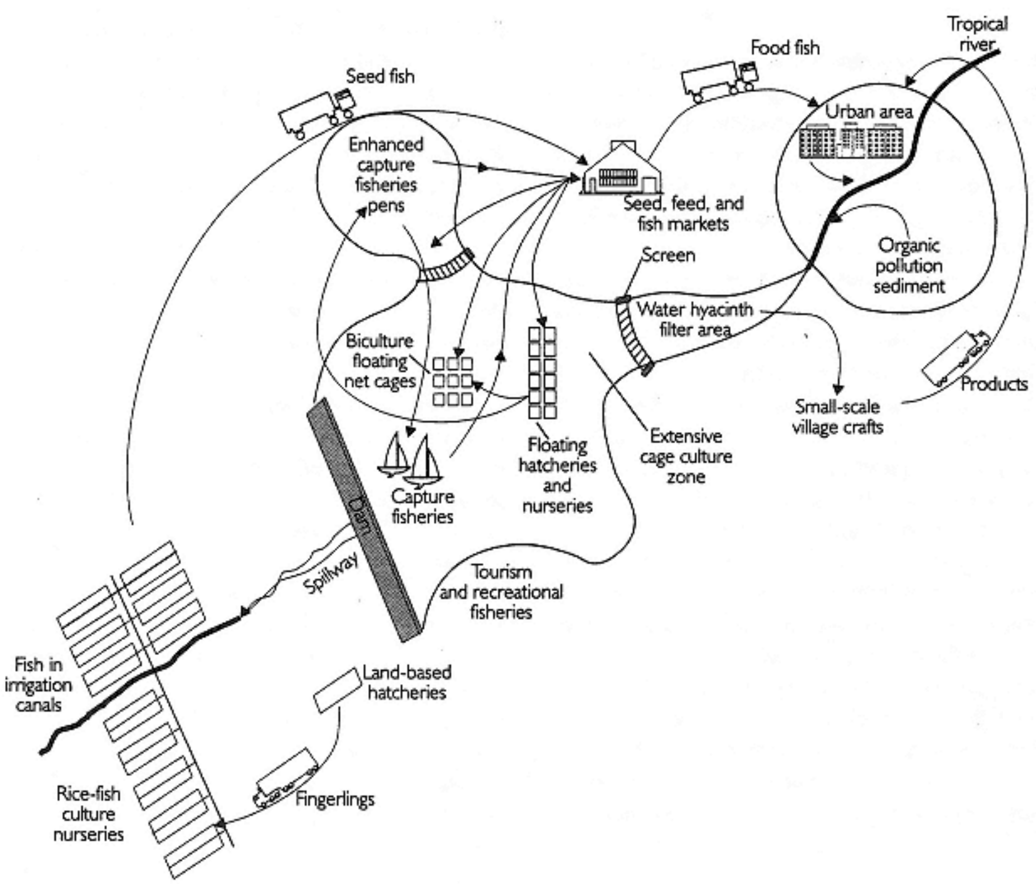

Figure 8
Integrated fisheries systems open up a range of possibilities for employment and environmental rehabilitation
Note: Figure is modeled on the Saguling and Cirata Reservoirs in 198693.

barrier, across the river to prevent downstream spread of the hyacinths. Neither effort was effective.

An alternative solution based on an ecosystems approach proposed developing, with community involvement, low−cost, aquatic plant and no−feed cage culture fisheries systems as nutrient filters and weed barriers. This solution used the aquatic plants and waste nutrient stream as "misplaced" resources that could be incorporated into new, productive enterprise systems. A water hyacinth filter was erected at the point where the nutrient−laden water enters the reservoir, to capture nutrients and to utilize sunlight for productive purposes. Downstream from the water hyacinth filter no−feed cage culture was developed, based on tilapia stocked at low density and filter−feeding Chinese carp (Costa−Pierce and Hadikusumah 1995). The aquatic plants and fisheries harness the fertilizing effects of the sewage to both mitigate pollution at a low cost and produce fish.

The water hyacinths also supported the development of small−scale cottage industries. Water hyacinths growing in nutrient−laden waters produce long, strong fibers suitable for making garments, handbags, and shoes. Knowledge on fabricating handbags from water hyacinth fibers in cottage industries was available in the town of Pekalongan, in Central Java.

Drawdown Agriculture, Agroforestry, and Erosion Control

Besides fisheries, another element of an integrated land−water ecosystem is agriculture—livestock or crops—in the reservoir drawdown area. Most conventional farming methods are unsuitable for the drawdown area, however, especially for crops requiring regular application of chemical fertilizers and pest control methods.

Moreover, drawdown agriculture is unsuitable for hydropower reservoirs where there is little predictability of the magnitude of drawdown. In the first few years after impoundment of the Saguling Reservoir farmers attempted to grow rice and vegetables in the fertile soils of the drawdown area. But after the crops were repeatedly drowned, many farmers abandoned the area, which was then converted to grazing land.

Land above the drawdown area in Saguling, however, is being intensively cultivated with multiple crops. Farmers report that easy access to water ensures them a crop even when farmers elsewhere suffer from drought. Farmers also take advantage of the highly fertile soil in the drawdown area, moving it to the land they cultivate above the drawdown area.

Bamboo forests have been established above the high−water mark of the reservoir, and they have been expanding to meet the demand for bamboo created by the new cage aquaculture industry. Each 7x7 meter fish production cage required 26 bamboos for initial construction. About half the bamboos needed replacement within two years, and all needed to be replaced within four years (CostaPierce and Hadikusumah 1990). In 1993, with 1,062 cages in operation, new bamboo forests had been planted in many areas around Saguling and Cirata. These forests undoubtedly are helping to control erosion and sedimentation in the watershed. Yet despite their presumably positive effects, no advance planning for the role of bamboo in the aquaculture ecosystems had been done.

In the drawdown area of Lake Kariba, in Zambia and Zimbabwe, a grass (*Panicum repens*) was planted that has the remarkable ability to remain alive even when submerged for many months. At reemergence, the grass recovers and flourishes, covering wide swaths of Lake Kariba's drawdown zone in a rich, green carpet and helping to reduce wave erosion. During the dry season thousands of animals from the savannah come to the drawdown area to graze, leaving tons of manure. The manure fertilizes both the grass and the large reservoir's productive littoral zone. A herbivorous tilapia (*Tilapia rendalli)* was introduced to utilize the new feeding area (Caulton 1977).

Economic and Sociological Issues of Resettlement

From a national perspective, hydropower is a clean energy source, tainted only by its environmental and social impacts. From the perspective of the rural communities affected, however, hydropower involves sacrifices that are not equally shared: Urban people get cheaper power, rural people get displaced. Asia, with most of the world's mediumsize hydropower reservoirs and high population density in rural areas, has undertaken most of the world's reservoir−related resettlement efforts (De Silva 1988a). For example, as originally planned, at 250 meters high, the Pa Mong dam in the Lao People's Democratic Republic (west of Vientiane) would have inundated 3,700 square kilometers of land and displaced about 250,000 people in that country and Thailand (Hiebert 1991). A study of 39 dam projects in Asia financed by the World Bank in 197985 showed that they displaced about 750,000 people in 27 countries (Cernea 1989). Cernea (1991) cites studies from China and India indicating that dam projects in these countries may have displaced up to 30 million people over the past 40 years.

Resettlement has the following characteristics: It is compulsory—people must move or be moved. It involves entire communities—young and old, conservative and liberal. It is a process that begins with rumors and ends only when people are finally settled in their new homes. It involves dismantling the production systems on which people depend for their incomes and livelihood. And it involves stresses that increase the incidence of disease

(Goldsmith and Hilyard 1984 and 1986). In densely populated rural Asia the damming of a river creates enormous problems as a result of the displaced people's loss of their traditional homes and land—including cultural, economic, and mental and physical health−related problems. There are increasing reports of violence and social upheaval.

The problems arising from resettlement are complex. They require clear thinking about the balances that need to be achieved and the processes that will be used to reestablish the economic health of communities and the health of the environment. Every development effort has both positive and negative aspects—both winners and losers. The challenge is to include as many segments of society—rich and poor—as possible, to call attention to gender−related biases, and to ensure that the benefits of development are shared as equitably as possible. Planning for new land−water ecosystems may be the most rational approach for meeting these challenges.

Planning for Resettlement Fisheries

Resettlement requires large expenditures and a commitment to a long−term process that must be incorporated into the plans for a dam and reservoir project at the initial stages. In the 1970s many resettlement efforts were not initiated until construction or engineering preparations for the dam had begun. Governments' and lenders' lack of knowledge about and experience with resettlement led to a huge underestimate of the time needed to adequately (and peacefully) resettle people. The result was crash programs laden with tension and conflict and the movement of thousands of displaced people to new areas where, in many cases, the extant land−water ecosystems could not support them. As a result of these experiences, the World Bank has drawn up guidelines for projects it supports that involve resettlement (box 3).

There is no one solution or set of solutions to the technical, social, cultural, ecological, and financial challenges of resettlement. The major challenges are these:

Initiating and timing resettlement programs.

Box 3 World Bank guidelines for resettlement

Cernea (1988) has reviewed the issues of involuntary resettlement for the World Bank and developed technical checklists for preparing, appraising, monitoring, and evaluating resettlement plans, and guidelines for economic and financial analyses of project components addressing resettlement. The key objective in all Bank−supported resettlement is to provide displaced families with the means to restore lost incomes. Thus, developing new production sources is the core requirement. In land−scarce Asia meeting this objective requires innovative thinking.

The World Bank requires completion of a resettlement plan that details the government's responsibilities, the resettlers' participation, and aspects concerning the host populations. The objective of the World Bank is to:

help the borrowing country ensure that, after a transition period, the displaced people regain at least their previous standard of living and that, so far as possible, they be economically and socially integrated into the host communities. In pursuing such integration, the major objective is to ensure that settlers are afforded opportunities to become established and economically self−sustaining in the shortest possible period, at living standards that at least match, and if possible improve upon, those before resettlement. (Cernea 1988, p. 19)

The World Bank's operational directive requires that resettlement plans

incorporate three distinct sets of activities concerning: (i) the preparation of the affected groups for the transfer; (ii) the transportation of the displaced to the new site; (iii) the integration of the displaced into the new community. Preparation of the resettlement component may require expertise in many disciplines, and should normally involve the on−site services of at least one sociologist/anthropologist, preferably from the country, and a specialist in resettlement. (Cernea 1988, p. 35)

Restoring production systems on a sustainable basis.

Establishing communication links to support participation by communities.

Implementing an integrated regional development plan for ecosystems and human systems.

Developing a long−term monitoring and evaluation process.

Resettlement plans should be initiated so as to coincide with any serious negotiations on physical works. They should include a detailed environmental impact assessment, covering all major aspects of the ecological and social impacts of resettlement. They should also include studies of the local traditional food systems, health status, education, housing, land use, social structure, and administration. Preinvestment feasibility studies should include:

A description of the status of the communities based on ecological, agricultural, water, and fisheries surveys.

Demographic studies.

Assessment of the health status of the population and the possibilities of disease transmission.

A land inventory and a description of land use and soil capabilities.

A description of the communities' traditional knowledge systems and the innovativeness, abilities, and education status of those to be resettled.

A description of the traditional farming and fishing ecosystems using participatory approaches.

Part of the reason for the frequent failure of resettlement projects is the fundamentally different premises held by project personnel and the people who are displaced. Governments tend to impose their plans, neglect to take the time to establish meaningful dialogue with communities to accurately identify their concerns, and fail to make the displaced people aware of the range of new opportunities opened to them by the new reservoirs and new land−water ecosystems.

Community participation needs to be given more than lip service. Mechanisms to involve the communities to be displaced should be initiated

well before any physical works (Cernea 1988). The longer−term social goals of a reservoir and dam are nearly always unclear to those who will be most affected by them. Conflicts arise when the goals of a dam are articulated only in economic terms, and in a way that implies that the dam and reservoir project will involve only sacrifice for the communities affected.

Dams need to be explained within the broader context of the future development needs of these communities and the needs for rehabilitating and enhancing ecosystems. Local resettlement plans should be a part of overall government plans for regional and rural rehabilitation and development. Resettlement needs to be explained to those affected not as a win−lose situation that can be addressed through simple compensation, and not solely in terms of the benefits to the nation as a whole, but also in terms of local benefits, local development, and local jobs.

Simple monetary compensation for displaced people is not an optimal solution for resettlement if the means exist to restore natural ecosystems, to preserve traditional knowledge in ecosystem management, and to create methods of developing new, integrated land−water enterprise systems that can intensify the use of the new reservoir ecosystem and help to restore or improve the economic and social conditions of those displaced.

A Consultative Process

Planning to incorporate fisheries ecosystems and integrated land−water enterprises into hydropower and irrigation projects must be done at the projects' design stage. But this kind of planning does not occur anywhere, probably because of the extra time and money required to establish effective communication links across professional groups not normally associated—engineers, sociologists, biologists, and environmentalists.

Developing integrated reservoir fisheries ecosystems requires establishing a process for preparing plans that detail the range and complexity of the problems. The key is to formulate new links and establish a consultative process that:

Recognizes all parties involved in the river basin development: the people affected, their institutions, arbitrators, nongovernmental organizations, and local, provincial, and national governments. Every effort must be made to establish an inclusive setting. Existing institutions need to be evaluated beforehand to see whether they need strengthening to carry out a comprehensive, participatory planning process, or whether a special agency needs to be created, such as a river basin commission.

Recognizes the equal importance of the engineering, social, and environmental aspects of the project, and establishes a commission that incorporates the dam and reservoir project and its impacts into a regional development and management plan for the local society and environment.

Establishes trust in a process of participatory consultation before any engineering works or other actions are initiated, and establishes written working agreements for the parties involved that detail the process, the requirements from the different parties, the reporting structure, and the processes for resolving conflicts and reporting their resolution. Such a consultative process is not a one−time event, but a continual, evolving activity.

Determines project objectives holistically, taking into consideration engineering, management, social, resettlement, and environmental aspects (figure 9).

Develops cost−benefit analyses of development programs and social and environmental restoration and rehabilitation programs.

Considers new opportunities, tradeoffs, and constraints, then produces strategies for optimizing and mitigating the outcomes of decisions.

Determines priorities.

Reexamines its decisions and priorities in the light of the original project objectives and revises them—and the objectives—as agreed to be necessary.

A Five−Phase Planning Process

Each river basin development project is unique, and its coordination and planning must be adapted to the local environment and social and economic

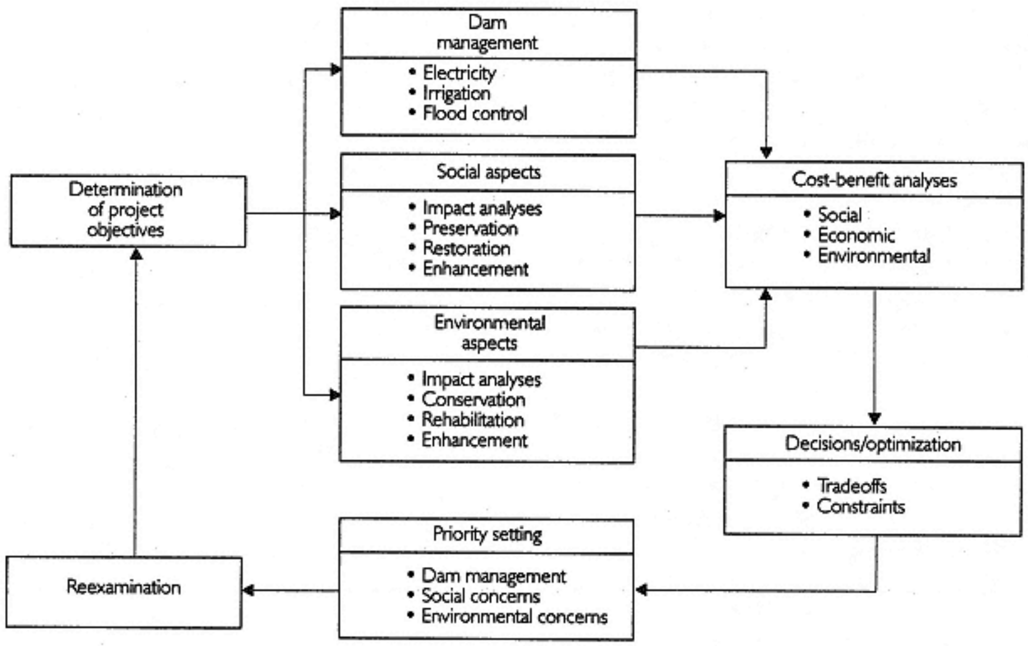

Figure 9
A consultative process is needed that puts social, environmental, and engineering objectives on an equal footing

systems. Planning requires close, continuous interaction with the people affected and with the local decisionmaking and political processes. A fivephase planning process is envisaged for incorporating fisheries ecosystems into a long−term regional development plan for resettlement from river basin projects.

Phase 1: preparing background studies, feasibility studies, reports on the social and political status of the affected communities, and preliminary recommendations. Phase 1 studies should document the society's organization, community traditions and practices, government structures, and relevant laws, regulations, policies, and responsibilities. The studies should use rapid appraisal techniques to evaluate major natural, agricultural, and economic systems and their forms and functions in society. The goal is to come up with a preliminary set of recommendations addressing the major issues and priorities for action. The work in this phase is crucial in determining the possible impacts of the project.

Phase 2: formulating an integrated development and management plan for land and water ecosystems to support local resettlement. This phase occurs after the decision has been made at appropriate government levels to proceed with the project. During this phase an implementation plan for integrated reservoir fisheries ecosystems is developed, at the same time as plans for dam engineering and construction.

Formulating a local resettlement plan that develops alternative livelihoods—such as integrated fisheries ecosystems—is a lengthy process that should begin before planning for engineering works. Delaying planning for local resettlement and for integrated reservoir ecosystems until dam construction begins leaves too little time for the planning process and for creating the web of essential connections to the communities affected.

Phase 3: involving community leaders and groups in formulating and assessing plans and contracting with or forming nongovernmental organizations (NGOs) to assist in the project. This phase is often the missing link in resettlement, especially where governments tend to shroud projects in technical details. As Cernea (1991) states, "forced population displacement, even by size alone, is the most significant variable in river basin development. Yet current thinking and planning patterns do not recognize it adequately, either in terms of its magnitude and real costs, or in terms of its social consequences" (p. 8). Too often, active community participation in planning for the livelihoods of the displaced people, and for rural roads, electrification, potable water, sanitation systems, and food production, is given only lip service. Little attention is paid to setting aside adequate funding to create new community structures that can regularly evaluate and, if necessary, redirect resettlement efforts. Forming NGOs that include community leaders can be an important part of this interactive process. But these new organizations must consider the community relationships with the new ecosystems created. They must also be adequately funded and supported in their attempts to establish new processes for discussion and compromise.

Phase 4: preparing progress reports, including reassessing plans and charting progress through the stage in which the reservoir fills and the ecosystem is unstable. This phase focuses on monitoring the society and the new ecosystems during what is for both the most critical stage of the project. In this phase the best−laid plans can go seriously awry unless a system of rapid assessment, reporting, and communication is established. The agreed−on process for resolving conflicts must be in place before this phase.

Phase 5: reevaluating and, if necessary, reformulating the resettlement plan after a period of monitoring and of drawing lessons during the stabilization of the reservoir and from operational experience with the new ecosystems and the dam and other major structures. During this operational phase the integrated reservoir fisheries ecosystems are developing rapidly and institutional structures are adapting or need to adapt to cope with the changes.

Resettlement in Saguling and Cirata through Intensification of Integrated Land−Water Ecosystems

Construction of the Saguling and Cirata dams in 1986 and 1988 displaced more than 120,000 people in West Java, Indonesia. In 1986, with funding from the World Bank, ICLARM and the IOE undertook a collaborative project to develop integrated fisheries and aquaculture options as a means of social and environmental rehabilitation. Extension, training, and research were conducted to resettle 3,000 families (1,500 each in Saguling and Cirata) in reservoir cage aquaculture or fisheries−related industries (Costa−Pierce and Soemarwoto 1990b). The project was the first to examine in detail the potential role of fisheries in a resettlement effort associated with a tropical hydropower project. Its results demonstrate the potential social and environmental benefits of reservoir fisheries development when holistic ecosystems development and management approaches are pursued with appropriate institutional support and development assistance.

Progress in developing the integrated fisheries enterprises has been excellent. By the end of 1992 cage aquaculture systems in the Saguling and Cirata Reservoirs (flooded in 1985 and in 1988) employed an estimated 7,527 people (1,162 owners and 6,365 workers). In 1992 cage aquaculture systems produced 10,047 tons of fish—compared with an estimated 10 tons a year produced from the original river fisheries in 1985 (figure 10).

The fish production from the reservoirs was estimated to have increased the fish supply entering the greater Bandung district, an area of more than 3 million people, by more than 25 percent. At the end of 1989 revenue from fish was estimated at Rp 5 billion a year, some 2.6 times the estimated Rp 1.9 billion in revenue from the 2,250 hectares of rice flooded by the dam (IOE and ICLARM 1989; see box 4).

In 1985 the Institute of Ecology of Padjadjaran University conducted a study of Saguling that showed that after relocation, the incomes of displaced families were 49 percent lower and their

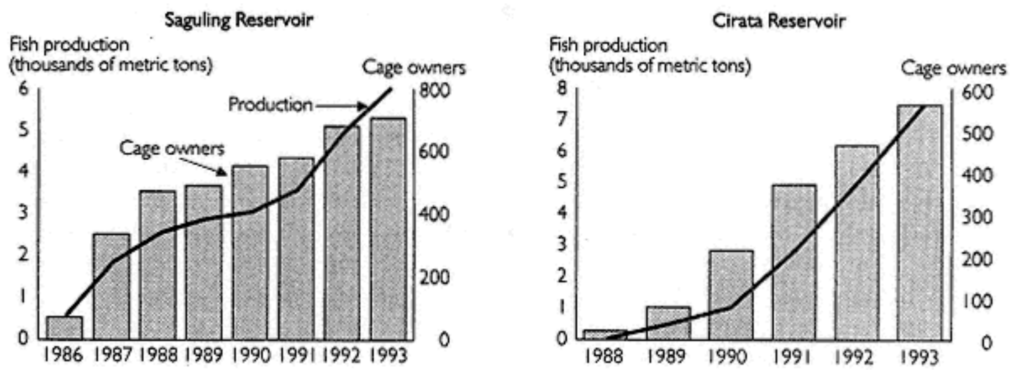

Figure 10
Resettlement fisheries grew rapidly in the Saguling and Cirata Reservoirs
Source: Reservoir Fisheries Technical Unit, West Java Provincial Fisheries Service.

land ownership was 47 percent lower (IOE 1985). In 1989 an IOE study of those displaced from Cirata found that 59 percent had higher incomes after relocation and 21 percent were worse off (IOE 1989).

Most of the displaced people who have increased their incomes and status in the Saguling−Cirata project have been participants (as owners or workers) in the resettlement strategy, which has focused on intensifying and integrating uses of the reservoir surface and surrounding land to develop new, interactive land−water ecosystems (Soemarwoto 1990; Sutandar and others 1990). Such environmentally oriented resettlement efforts fully utilize the new water surface for aquaculture and fisheries, and develop supporting production, economic, and infrastructure systems to support this industry and to promote the recycling of resources from one local enterprise to another. This option is especially attractive in Asia, where a majority of the people rely on fish as their main source of animal protein and where a wealth of knowledge exists on traditional water resources management practices and on both traditional and modern aquaculture technologies.

A comprehensive fisheries ecosystems development and management approach to resettlement fosters close interaction with the affected communities to extract technologies that have been traditionally proven and adapted to the new resource base and to create new productive enterprise systems that use as much as possible the rich traditional knowledge base in these rural communities.

Resettlement necessitated by the construction of a reservoir involves a dramatic shift from a predominantly land−based agricultural society to a water−based fisheries society. But in many parts of Asia people have traditionally integrated fisheries into complex agricultural and ecological systems to meet their needs. Integrated reservoir fisheries ecosystems have flourished in the Saguling−Cirata region of Indonesia, where as many new jobs were created in spin−off or support industries as in the new fisheries enterprises.

The examples of Saguling and Cirata show that under the right conditions, integrated fisheries development can greatly enhance the economic and social benefits from hydropower and irrigation projects in some developing countries. The success of integrated fisheries development in providing alternative livelihoods for those displaced by new reservoirs is best proved by the actions of those affected. During the early 1990s reports were received at regional fisheries offices at the reservoirs that many of those who migrated from the areas in 198688 have returned. These people were attracted by reports of better economic and living conditions due in part to the opportunities offered by the new land−water ecosystem and integrated fisheries systems developed at Saguling and Cirata (Effendi 1992).

Box 4 The economics of Saguling and Cirata

The Saguling dam, a high dam intended for peakload power generation, was completed in 1985 at a cost of $665,897,000, and Cirata, a lower dam for base−load power, was completed in 1986 for $565,000,000. Revenue from sales ofSaguling's electricity consistently exceeded $500,000 a day in 1992 (Supramoto 1993). Under a conservative assumption that this revenue could be sustained for 200 days a year, Saguling is a very profitable project with a payback period of less than seven years. A similar scenario can be put together for Cirata.

Estimated 1992 fisheries revenue for Saguling and Cirata was $10.05 million (10,047 kilograms ≥ Rp 2,000 per kilogram at an exchange rate of Rp 2,000 to $1). Assuming an annual revenue from electricity of $200 million for Saguling and Cirata, fisheries generate only an estimated 5 percent as much revenue as power generation.

But when looked at from the standpoint of agriculture, the revenue from the reservoir fisheries is impressive. In 1984 the estimated revenue from the 2,250 hectares of rice flooded by the Saguling dam was $1.68 million, or $747 per hectare. At Cirata, where the quality and price of rice are higher, a price of $1,000 per hectare is assumed (IOE 1987), and the revenue from the 3,533 hectares lost is therefore estimated at $3.53 million (IOE 1992). So the estimated loss of revenue from rice is $5.21 million a year—just 52 percent of the estimated revenue generated by only 1,062 aquaculture cages in 1992.

The IOE and ICLARM (1989) recommended that 1 percent of the reservoir surface area (5,300 hectares at Saguling and 6,200 at Cirata) be developed for cage aquaculture. That would mean 11,500 fish cages at the industry's maturity. If each of these cages produced a conservative estimate of 3 tons a year (Costa−Pierce and Hadikusumah 1990), the fisheries would generate $34.5 million a year at 1992 prices.

Accelerated Learning in Cirata

Construction of the Cirata hydroelectric power plant began in 1983 and operations in 1988. The reservoir caused a loss of more than 50 percent of the rice land in the area (IOE 1988). This loss occurred in an area where the lack of growth in employment in rice and vegetable cultivation was of major concern in the 1970s and the labor absorption capacity was forecast as virtually nil (Collier, Hadikoesworo, and Saropie 1977).

But by 1988 reservoir fisheries operators, institutions, and extensionists in Cirata had already achieved as much as in the nearby Saguling Reservoir, where fish production was about 2,500 tons a year, and their successes were being widely disseminated by word of mouth among the displaced people (Costa−Pierce 1992a). A large extension and training effort for displaced residents from Cirata had been under way since 1986. The success at Saguling prompted 70 percent of the displaced people at Cirata to relocate to the area around the new reservoir and to take the risk of changing their livelihoods. Only 26 percent of the people chose to migrate (IOE 1988).

As a result of the demonstrated successes at Saguling, fisheries development proceeded in Cirata even more rapidly than the breathtaking pace at Saguling. From nearly zero in 1988, fish production reached 5,000 tons in 1992, produced by 469 owners (see figure 10).

The number of rice farmers at Cirata has declined and the number of cage aquaculture workers and boat owners and drivers increased. Before the reservoir was inundated, male seasonal agricultural workers would earn Rp 2,000 a day and women Rp 1,500 a day during a 36−day season. Many of these workers now work as employees in the cage aquaculture industry, receiving Rp 20,000 per cage a month. Those who manage a four−cage unit (including a guardhouse) earn Rp 80,000 a month. The IOE (1992) reports a wage difference between rice field workers and cage aquaculture workers of Rp 56,000 a month.

The integrated fisheries systems have increased the number and diversity of jobs and the number of higher−paying jobs. The IOE (1992) documented 22 new types of jobs generated directly and indirectly by the new fisheries enterprises (table 3). New developments in tourism and a planned resort will further increase job opportunities. In a 1992 sample of displaced people, 29 percent were employed in jobs related to the new reservoir ecosystems (86 percent of them men, 10 percent women, 3 percent children; IOE 1992).

A split between young and old has occurred, with most of the remaining traditional agricultural systems managed by older people while young people are more likely to invest in new, water−based fish−

Table 3 New employment opportunities and wages of people resettled at the Cirata Reservoir, 1992 (*rupiah)*

Type of employment	Income or wage
Fish cage mar.ager	100,000166,667 per month
Fish dealer	200,000 per month
Cage feeder	80,000 per month
Full−time fisher (capture fisheries)	4,0006,000 per day
Raft fisher	24,000 per month
Part−time angler	120,000168,000 per month
Boat rower	72,000120,000 per month
Raft operator	144,000288,000 per month
Barge driver	120,000144,000 per month
Public transport driver	144,000 per month

Stall keeper	120,000720,000 per month
Construction worker	840,000 per month
Manual laborer	120,00240,000 per month
Snail collector	500 per kilogram
Shrimp collector	1,000 per kilogram
Cage mover	35,000 per cage moved
Net retriever	35,000 per net
Fish middleman	10,000 per cage
Boat maker	150,000 per boat
Boat driver	—
Drawdown agricultural worker	—
Tent maker	—

—Not available.

Source: IOE 1992.

eries enterprises. A disporportionate share of the cage aquaculture owners and employees are under age 45. In a number of cases people have sold rice land to purchase cage enterprises. Many young people have observed that cage aquaculture is easy and enjoyable work that allows much leisure time, in contrast to the back−breaking toil in the rice and vegetable fields of their elders.

Since the inundation of the reservoir, new forms of community organization have arisen that are knowledge−based, relying on skills and education. Fisheries cooperatives, schools, a labor service for cage aquaculture, and a cage fish farmers organization are active in Cirata.

Equity Effects of Resettlement Fisheries

In developing reservoir fisheries ecosystems to support resettlement, user rights must be defined in a binding contract between an arbitrator (usually a government authority), the developer (usually an electric power or irrigation authority), and the people affected by the reservoir. It is difficult to ensure equity among those who are resettled, however. Inequitable distribution of the new aquaculture enterprises and the concentration of available capital in the hands of a few result from a number of factors, including the preexisting landownership patterns, weak regulations and poor enforcement, and the sale by local people of their resources for short−term gains or, in cases of extreme poverty, for basic survival.

At the Saguling and Cirata Reservoirs the benefits of the new cage aquaculture enterprises have accrued mainly to those with relatively more capital and power. Most of the poorest displaced residents are workers in the cage aquaculture industry rather than owner−operators controlling its development.

Equity problems have arisen despite legislation passed by the provincial government of West Java stipulating that the waters and drawdown areas of the Saguling and Cirata Reservoirs were for the exclusive use of the people displaced from the inundated areas. The legislation specified that permits to enter the cage aquaculture industry were to be issued by the West Java Provincial Fisheries Department only to displaced people. Each displaced family could obtain a permit to operate a single−unit enterprise, defined as a maximum of four 7 ≥ 7 meter cages and a guardhouse.

The legislation and permitting system to control entry were not adequately enforced, however. IOE (1992) surveys found a few rich families operating more than 100 cages. According to 1992 records of the Fisheries Department, 57 percent of permits were given to displaced people and 43 percent to people not affected by the project. Cage owners from Bandung, Jakarta, Cianjur, and other cities were found operating in the reservoirs.

The intent of the legislation was undermined in several ways. Fisheries officials issued permits to people whose residence of record was the area of the reservoir without requiring proof that they had actually been displaced by the project. Some of the poorest of the displaced people sold their rights to outsiders on the condition that they would be employed as an aquaculture farm manager or worker. Others developed cages in their own names and then rented them to outsiders. And some families were able to subvert the regulations by claiming that each family member, including all members of the extended family, had a right to one unit of cage aquaculture (four cages). Among the families that acquired more than 100 cages, some were able to diversify into the provision of feed, fish seed, and credit and marketing services, gaining undue control over the new aquaculture industry.

But the cause of the equity problems in the cage aquaculture industry extends beyond the use of connections to get permits. Land inundated by the Cirata Reservoir was owned not only by local people but also by outsiders. The IOE (1992) estimated that resettlement plans for Cirata involved the compensation of 8,459 resident families and 2,593 nonresident families that owned land in the area. There was much less nonresident landownership in Saguling, probably because it is farther away from the urban centers of Cianjur, Bogor, and Jakarta.

One way to adequately police the use of fisheries resources is to fully privatize the rights to their use. In reservoirs, for example, exclusive, nontransferable permits to conduct cage aquaculture could be issued to families. Under such a scheme, originally suggested by Munro, Iskandar, and Costa−Pierce (1990) for privatizing Saguling's capture fisheries resources, permanent permits to conduct cage aquaculture would be issued to a limited number of families, determined by the ecological carrying capacity of the reservoir. Licenses would be valid for the lifetime of the head of the family and could not be sold or transferred without permission of the authorities. No additional licenses would ever be sold. All those who held licenses would know who the other licensees were, so that responsibility for policing the resources and determining abuses would be theirs. Since outsiders could be readily identified, policing would improve.

Access to capital also has effects on the equity of aquaculture development. Even the low−cost cage aquaculture models developed by Costa−Pierce and Hadikusumah (1990) and others, and promoted and recommended by the IOE and ICLARM (1989) in their reservoir fisheries and aquaculture development plan for Saguling and Cirata, have proved too expensive for the poorest of the displaced residents. In addition, the poor could not get access to capital from conventional sources because they lacked adequate collateral. In some cases land speculation and inflation have played a part: with the higher prices caused by speculation, many could only afford to buy a smaller piece of land than they had owned before the reservoir was created (IOE 1988).

In a survey of 365 displaced residents in the Cirata Reservoir area, the IOE (1992) found that 20 percent owned cages. Among the 80 percent who did not, 91 percent reported that they did not have enough capital, and 76 percent of these respondents stated that they wanted to enter cage aquaculture once they had saved enough. For those already in the industry, capital had come from compensation money (26 percent), returns on agricultural (3 percent) and nonagricultural ventures (16 percent), loans (23 percent), savings (12 percent), and sales of land (10 percent). Some of the more entrepreneurial people had saved their compensation money, bought land, and then sold it and used the proceeds to start new fisheries enterprises (IOE 1992).

Those who own cages could expect to earn an income of Rp 300,000500,000 per cage every three to six months. But owning cages—or working in the cage industry, as the poorest residents tend to do—turns out not to be the only way to profit from aquaculture. The many fish lost from the cages during stocking and harvesting have led to the development of significant capture fisheries for the poor who lack access to capital for aquaculture. More than 580 displaced poor people were found to be capture fishers in 1992 (IOE 1992). They caught an average of 2.9 kilograms a day, earning Rp 5,0405,800 a day from this activity, more than the national minimum daily wage.

The development of the Cirata Reservoir and the new fisheries enterprises has also had gender−related equity effects, causing a shift in employment patterns for men, women, and children. The IOE (1988) reported that, before inundation, most residents were occupied in agriculture. But a November 1992 survey showed that while most men and children had moved into fisheries occupations, women had entered business as small shopkeepers or were working as housewives (table 4). Many women were unemployed. The cage aquaculture operations are considered largely "men's work," and opportunities to work in agriculture are limited because of the loss of more than 50 percent of the productive agricultural land in the area.

Nutritional Impacts of Resettlement Fisheries

Fish from reservoir fisheries can contribute to nutrition directly, through their consumption, or indirectly, through their commodity value. Under some circumstances the poor will benefit more from direct consumption of the fish; under others they will benefit more from selling the fish and using the income to purchase food. The commodity value of fish is important to poor communities that need to improve not only their nutritional status but also their overall quality of life (Kent 1987).

Fisheries and aquaculture products may not help in meeting nutritional needs when:

- Aquaculture products are exported.
- Aquaculture products are consumed by the rich.
- Income from fisheries is diverted.
- Fisheries operations take time and labor away from subsistence crops important to nutrition.
- Increased fish consumption results in decreased consumption of other nutritionally important foods.

Table 4 Survey respondents involved in new occupations at the Cirata Reservoir, by type of employment, November 1992 (*percent)*

Type of employment	*Men*	*Women*	*Children*
Cage grow−out farmer	39	4	0

Hatchery farmer	1	0	0
Laborer	30	4	50
Feed broker	2	0	0
Fish broker	2	4	0
Fisher (capture fisheries)	14	0	0
Boat owner	8	0	0
Boat driver	14	0	17
Land transport worker	1	0	17
Shopkeeper	6	59	17
General laborer or peddler	11	0	17
Other	0	27	0

Note: Numbers do not add to 100 percent because many people hold multiple jobs.

Source: IOE 1992.

High−tech aquaculture overtakes subsistence aquaculture, producing the wrong species at the wrong time for the wrong people (Kent and Josupeit 1989).

The reservoir region in Indonesia was found to have surprisingly low average annual fish consumption: 5.8 kilograms per capita of fresh fish and 6.6 kilograms of salted fish (12.4 kilograms in total) in the Saguling area, and 8.0 kilograms per capita of fresh fish and 3.8 kilograms of salted fish (11.8 kilograms) in the Cirata area (Costa−Pierce 1992d). The national rate is 15.05 kilograms per capita a year. The higher consumption of inexpensive, dried, salted ocean fish compared with fresh fish indicated that inadequate income was a limiting factor in fish consumption in the 16 villages monitored.

As Kent (1987) has pointed out, it is important to distinguish between development of fisheries to increase production and development of fisheries to enhance their contribution to nutrition. It can be argued that in Indonesia's reservoir region the cage aquaculture industry benefited the poor by increasing their incomes and thus enabling them to purchase a wider variety of food and improve their nutrition. But it can also be argued that, because almost all the large fish produced in the commercial cages were exported to urban areas, the industry benefited the urban rich more.

The truth lies somewhere between these two extremes. The cage aquaculture industry in the Saguling and Cirata Reservoirs did provide more jobs at better pay and with better working conditions than had been available in agriculture before inundation. The increased employment and income certainly contributed to better livelihoods and possibly to improved nutrition. But it was observed that poorer residents who operated cages sometimes purchased inexpensive, low−quality salted ocean fish rather than eat the higher−quality fresh fish from their cages. Large fish were consumed only on special occasions, such as weddings and holidays. Moreover, the children of a few cage operators exhibited nutritional deficiencies. When queried, these farmers admitted that they had sold fish to purchase consumer goods and a vehicle.

The IOE and ICLARM (1989) observed that although the poorest of the reservoir residents had little capital available for starting aquaculture operations, they were actively involved in capture fisheries. Given the preference of most of the poor for dried, salted ocean fish (Costa−Pierce 1992d), the introduction from Thailand of a small, open−water (pelagic) freshwater sardine was proposed to improve food security for these people (Costa−Pierce and Soemarwoto 1990).

In planning reservoir fisheries, it is essential to consider local preferences. Just as fish species are important consumer preferences in many areas, so is the size of fish. In most of Asia (excluding China) the smallest fish are regularly prepared in many local cuisines. In some Asian cultures presenting large fish to a social gathering can have negative connotations: someone must get the head, someone the tail.

In a survey of 16 villages in West Java 85 percent of villagers reported preferring tilapia of 2550 grams, and 71 percent common carp of 67200 grams, over larger fish (Costa−Pierce 1992d). It is fish of these sizes that the large majority of people in Southeast Asia consume.

Sundanese people in West Java prefer small common carp to make a special steamed fish dish known as *pepes ikan.* Smaller tilapia are preferred for frying and eating whole. The fish are prepared so that the bones either "disappear" (dissolved into the flesh by long boiling), or are made crisp. These traditional ways of preparing fish not only provide high−quality fish protein but also yield important sources of calcium and phosphorus.

Lessons from Saguling and Cirata

Essential to the sustainable development of aquaculture is having the supporting pillars in place—the seed, the feed, and the need. The availability of inputs at an appropriate cost and quality and large market demand for farm−raised freshwater fish have been key in the success story of the Saguling and Cirata reservoir fisheries. Their development, and the use of fisheries as a meaningful resettlement option, depended on the presence of the following ingredients:

A defined target group. Problems in "agenda setting" can make fisheries development projects go awry from the outset. One of the main questions that must be addressed in defining clear objectives for a project is, Who and where is the primary target group (or groups)? In the Indonesian reservoir project the target group was clearly defined. Lists of family names with the addresses of the displaced people were provided by the state electric company.

Ready availability of capital. Aquaculture generally has a mixed to poor reputation among bankers and investors. Less well known than other agricultural enterprises, the business is widely considered excessively risky for all but investors with deep pockets. In the Indonesian project, however, investment capital was readily available from land compensation money.

Lack of alternative employment opportunities. In rural Java, one of the most densely settled areas in the world, existing agricultural activities could absorb little or no additional labor. With few alternative rural employment opportunities, aquaculture was a promising new enterprise.

Rich local traditional fisheries knowledge. The innovative farmers in West Java were quick to adopt integrated fisheries ecosystems. The farmers had a rich traditional knowledge of aquaculture, and commonly raised fish in paddies in complex rotations with rice crops or in backyard family fish ponds.

Large markets and social acceptability. There is strong market demand for freshwater fish. People prefer freshwater over saltwater fish and are willing to pay high prices. Fish provide about 70 percent of the animal protein in the local diet and also play an important part in the culture.

Adequate infrastructure. The local and national governments developed an adequate transport system that provided farmers with quick and ready access to large urban markets.

Dendritic reservoir. A dendritic reservoir (having numerous arms or fingers), Saguling had many deep, sheltered bays suitable for cage aquaculture and high surface and volume contact with the surrounding land, which makes it a rich (eutrophic), productive aquatic ecosystem.

Institutional agreements. Institutional agreements supported technical assistance to the new villages surrounding the reservoirs by the government, the electric company, a university ecology institute, and fisheries organizations, leading to rapid technological development and economic evaluations of new models of productive aquaculture enterprises.

A developed, segmented aquaculture production network. Indonesian freshwater aquaculture is an evolved, dynamic industry, clearly segmented into hatchery, nursery, and grow−out sectors. The development of the grow−out cages resulted in a dynamic restructuring of the aquaculture production network and lower−priced fish in the urban markets of Jakarta and Bandung.

Ready availability of seed and feed. Large seed markets and feed mills mean that production inputs are readily available in rural areas.

Offering equally important lessons for the development and management of reservoir fisheries are the problems that the Saguling−Cirata project has encountered:

Equity issues. There is a risk that the benefits of reservoir aquaculture development may eventually be transferred away from the target group. When the cage culture industry began to take off, rich people from Bandung and Jakarta began to enter the industry, and now dominate new cage aquaculture development. The displaced people are involved primarily as laborers, not owner−operators, in the capital−intensive cage aquaculture industry. In Saguling, for example, rich traders from Bandung and Jakarta have been illegally edging their way into the aquaculture industry (Rusydi and Lampe 1990).

Institutional coordination. The Saguling−Cirata fisheries project was not a model of institutional collaboration. The new working relationships and procedures created between disparate ministries and line agencies for this short−term project are unlikely to be sustainable.

Reservoir turnover events. Turnover events have occurred each year since Saguling was inundated. Interestingly, however, farmers continue to take the risk involved in raising fish. Interviews indicated that because of fish shortages during the season when turnovers occur (at the onset of the rainy season, when the ocean is rough and the supply of ocean fish therefore declines), fish prices are higher and the potential benefits more than offset the risk of fish kills. Moreover, dead fish still have value; they can be sold for 2050 percent of the price of live fish, depending on their state of decomposition.

Degradation of water quality. The increasing chemical pollution from the growing number of textile and chemical plants in the reservoir watershed areas could spell the death of the fisheries ecosystems in both reservoirs if adequate pollution controls are not put in place.

Institutional, Planning, and Management Needs in Developing Reservoir Fisheries Ecosystems

Institutional Concerns, Constraints, and Coordination

If the general kind of institutional framework needed to support the development of reservoir fisheries ecosystems for resettlement is known, achieving it nevertheless remains one of the biggest practical problems. The main constraint is the poor quality of the institutional coordination across sectors, or line ministries, that is needed to ensure that fisheries are included on the management agenda of tropical hydropower projects. There are several reasons for this poor institutional coordination. Government fisheries organizations tend to be weak. Fisheries are considered of secondary importance in the development of reservoirs. And not enough attention or resources are given to the coordination of ministries and agencies in reservoir fisheries development.

Fisheries activities are generally coordinated by government fisheries departments or are institutionally buried within ministries of agriculture. These fisheries departments are widely considered among the weakest agencies of governments. As a share of each sector's contribution to GDP, public support to fisheries is usually much less than public support to agriculture (ICLARM 1992).

By contrast, electric power agencies are among the strongest government agencies. Well funded, they command the attention of powerful policymakers. There is little awareness or concern in electric power organizations about the potentials and problems of fisheries. But for their part, fisheries developers often are far too technically oriented and unable to articulate the needs of fisheries in terms understandable to power officials.

The balance of power between fisheries organizations and electric power agencies is reflected in the ordering of priorities in reservoir development. No reservoir has ever been constructed with fisheries as the primary function. The fisheries components of hydropower or other reservoir projects have often had an add−on quality. Most are written into project proposals by development professionals without fisheries expertise and read as if fisheries were afterthoughts to the project, even when the fisheries will involve a large number of people. Developing reservoir fisheries is clearly secondary to the main purpose of reservoir construction.

The main development goal for reservoir fisheries, therefore, must be to ensure that they are compatible with the primary functions of water storage and dam operations. And the primary institutional goal is to create an institutional structure that not only can articulate clearly to policymakers the benefits of developing or enhancing reservoir fisheries, but also has the authority to carry out agreements between the agencies and authorities concerned.

The essential compatibility of integrated fisheries ecosystems with the primary activities of reservoirs needs to be recognized. Where fisheries are culturally and nutritionally important and markets are large, reservoir fisheries should be included as an integral part of the planning and management of dam operations. For dam operations that means that the timing of water releases should not only meet engineering considerations, but also ensure

the ecological stability and sustainability of the aquatic ecosystem and of the fisheries.

The institutions that need to coordinate their efforts to develop reservoir fisheries extend beyond the fisheries department and the power company. Also involved are communities, extension agencies, universities, and nongovernmental organizations.

The requirements for coordinating the efforts of these institutions are not given adequate attention. Simply stating that "the project will attempt to develop sustainable watershed management of the reservoir and will therefore require the collaboration of the ministries of water supply, environment, fisheries and electric power," for example, is not enough.

The Saguling−Cirata project provides a good example of the challenges and pitfalls of institutional coordination in reservoir projects. At the outset a nightmare web of new interactions had to be created and re−created between different levels of government and between government and nongovernment agencies that had never or rarely worked together before, including the electric company, the university, the department of fisheries, and provincial, regional, and village political institutions (table 5). Each of these institutions had different objectives and policy goals, and institutional agreements and project responsibilities were only vaguely defined. What resulted were numer−

Table 5 Institutions responsible for managing and monitoring activities at the Saguling and Cirata Reservoirs

Activity	*Institution*
Management	
Regional planning, including pollution prevention	Bappeda (district administrative office) and head office of PLN (state electric company)
Overseeing the planning	PLN head office
Execution and coordination of plans	PLN−KJB (PLN provincial office, Bandung)
Integrated management of Citarum River watershed	PLN, Public Works Department of Forestry Service, Jatiluhur Authority
Granting licenses for fishery businesses	West Java Fisheries Service (controlled by PLN−KJB)
Granting licenses for using drawdown area	PLN−KJB (in cooperation with West Java Agriculture Service)
Fishery extension	Technical Implementation Unit of West Java Fisheries Service (in cooperation with PLN−KJB)
Supervision and coordination	Cooperation Service (working with Fisheries Department of PLN−KJB)
Development of rabbit and earthworm farming	West Java Animal Husbandry Service (in cooperation with West Java Fisheries Service and BRLKT, the regional agricultural training agency)
Development of feed and hide industries	West Java Regional Department of Industry (in cooperation with West Java Fisheries and Animal Husbandry Services)
Soil conservation extension	BRLKT (in cooperation with West Java Agriculture and Animal Husbandry Services)
Health	Health Service
Tourism development	West Java Regional Tourism Office

Family planning development	BKKBN (regional family planning agency)
Skills training	BLK (regional job training agency)
Observation and advanced research	Competent research center (in cooperation with PLN−KJB)
Disseminating Saguling and Cirata model as a component of integrated river basin management	Competent research center (in cooperation with PLN−KJB)
Monitoring	
Fish population dynamics	Inland Fishery Research Center or competent research center
Aquaculture marketing	Technical Implementation Unit of West Java Fisheries Service (in cooperation with West Java marketing cooperatives)
Development of rabbit and earthworm farming and of alternative feeds	West Java Animal Husbandry Service (in cooperation with West Java Fisheries Service, BRLKT, and Industrial Development Department)
River water	Center of Research and Irrigation Development (in cooperation with PLN provincial office)
Reservoir water	PLN−KJB
Aquatic weeds	PLN−KJB
Heavy metals and pesticide residues in fish	Competent research center
Water temperature (for early warning of turnover)	Fish farmers
Catchment area of reservoir and upper river basin	BRLKT
Sedimentation of reservoir	PLN−KJB
Climate	PLN−KJB (in cooperation with Center of Meteorology)

ous overlapping authorities over resources and people.

At the project design stage little attention had been given to Indonesia's existing political structure and lines of reporting from the center to the provinces and regions. Tasks were assigned to the wrong levels of government, possibly because too little time had been allotted for detailed project design and preparation. And because the project agreement was vague, collaborating institutions frequently had their own interpretations of what it said and sometimes carried out those interpretations without communicating with others.

The interdisciplinary nature of reservoir projects further complicates their coordination. The Saguling−Cirata reservoir project had problems coordinating all the professionals needed to implement the integrated resettlement fisheries project, many of whom had difficulty seeing beyond the bounds of their narrow professional training.

An essential part of the solution to the coordination problems is to create a new authority for each reservoir development that has jurisdiction over the resources and can control the development for the benefit of the local people. River basin commissions have been created in some countries to manage such efforts. But in most developing countries different line ministries are responsible for different parts of an ecosystem, so that implementing watershed management or other ecosystemwide programs is extremely difficult. Petr (1985) stated that one of the major constraints to sound fisheries development in developing countries is the lack of coordinating river basin authorities, both during the planning and design of projects and during their implementation and management.

Long−term Management Concerns

The main management concern of integrated fisheries projects is long−term sustainability. One key to ensuring their sustainability is to institutionalize their management within the existing management systems of the power companies, fisheries departments, NGOs, and universities involved in the projects.

Anothier key is to undertake, over a long period, environmental and social assessments of the changes brought by these projects and of the effects of these changes. River basin development projects lead to new systems, natural and social, that evolve over time, both in structure and in function. For the first 10 years after inundation, dramatic changes occur in people's livelihoods, in communities, and in the lake basin as it adjusts to its basal fertility level and the management of water levels.

Currently environmental impact assessments (EIAs) are routinely required only during formulation and appraisal of hydropower projects. This assessment process needs to be extended over a longer period through careful, field−based monitoring that can last as long as 30 years after inundation. Periodic EIAs should address social and resettlement concerns, assessing changes in the environment and in society, evaluating priorities, and making predictions about both the problems and the opportunities occurring as a result of projects.

A continual EIA process could become an essential monitoring mechanism for charting progress toward the goals of a regional rural development plan. The process could be institutionalized by forming a monitoring agency, such as a river basin commission that retains responsibility for social and resettlement issues as well as engineering and environmental issues.

The management of integrated fisheries development is an evolving process that can be envisioned as comprising three 10−year phases:

First 10−year phase. Government subsidies are necessary to conduct demonstration, education, and training activities in community schools and to support a management office near the reservoir to monitor the rapidly changing ecosystems and the conditions of the people and to issue permits.

Second 10−year phase. Community demonstration and training activities are turned over to an NGO or to farmers groups, and monitoring functions contracted out to a university or a professional NGO.

Third 10−year phase. All monitoring, education, and permitting functions are turned over to a private enterprise, which finances its operations and its

services to producers through dues paid by the producers.

Many reservoir systems in Asia are in the second phase, but there are no known examples of fully privatized efforts.

Demonstration, Extension, and Training

Efforts to strengthen the organizational framework of reservoir fisheries must be matched by a solid understanding of how communities can take ownership of their new resources. Given the changed resource base, community−based training is essential, especially in alternative, water−based enterprises and other livelihoods that will not accelerate environmental degradation. Extension, training, and technical assistance play important roles.

Asian farmers have a large store of traditional knowledge of fisheries systems. In contrast to farmers elsewhere, they have the intuitive knowledge that fish can be raised much like any other farm animals. Thus, what is needed in many cases is not extensive education and training, but practical, hands−on demonstrations, exchange visits among farmers, and "social lubrication."

Connell (1990) defined an approach to participatory extension that he termed "minimalist": to deliver sets of viable technologies to farmers in diverse environments. Farmers are offered a "supermarket" or "basket" of technologies, allowed sufficient "creative distance" to evaluate the applicability of the technologies, then encouraged to identify areas for collaborative research (Conway 1986).

This approach seeks to elicit farmers' traditional agricultural knowledge systems and the opportunities and constraints these pose for adopting new farming systems. The results of applied demonstration and research are transferred to smallholder farmers, and feedback is sought from farmers so that demonstrations and agendas for applied research can be regularly revised. The main goal is to make large numbers of farmers aware of new options in a short time, and to develop low−cost extension methods that can be sustained after project financing ends and all activities revert to mainstream government or NGO extension services.

The idea behind this participatory approach is that the target group (the displaced farmers) must be involved in the process of developing and disseminating technology. Rather than developing one fixed set of techniques to extend to farmers, a basket of technologies is developed and demonstrated in a short period to thousands of farmers with vastly different amounts of capital available.

Farmers are invited to take part in the development and testing from the start. They can comment and criticize as much as they want; they can test new technologies at the demonstration sites, at field schools, or in the reservoir near their property; and they can modify technologies as they find necessary. Because the changes are made by the farmers, the approach is "evolutionary," not "revolutionary."

The responsibility for adopting a new technology rests entirely with the farmer. The farmer decides whether or not to try a new technology; farmers' refusal to do so is an important signal to the extension worker that something is wrong. And because farmers receive only information, not financial assistance or subsidies, they are not in a dependent position.

In the Saguling−Cirata project in Indonesia integrated fisheries technologies were rapidly disseminated to the displaced people through the development of community and village integrated fisheries systems centers. Each of these demonstration and information centers displayed a continually changing basket of technologies that could be of interest to farmers. Farmers were regularly invited to open days to view the technologies, given fisheries extension books (developed as comic books in the local languages), and provided lunch to allow time for informal conversations. They were encouraged to criticize the demonstrations and to suggest improvements or alternatives. Farmers were also encouraged to return to the village centers with their ideas, to stay at the site in order to acquire practical experience, or to come up with proposals to work on together at their sites.

All the extension and training methods presented were low−cost and sustainable and put the farmer first in developing technology appropriate for integrated reservoir fisheries. The methods

recognized the diversity of possible systems, the different applicability they might have for different farmers, the concept that no one technology is universally applicable, and that the farmer, not the extension worker, chooses the technology to apply. There are many ecological niches in tropical reservoirs, and farmers must be allowed to adopt and modify technologies to suit their circumstances.

Needs in Strategic Applied Research

Asia has a wealth of experience with reservoir fisheries, but little of the information from this experience is available to support national policymaking and research. In all Asian countries statistics need to be collected and analyzed on the number of current and planned reservoirs, on their biological, sociological, and fisheries management status, and on researchers' experience with these bodies of water.

Also needed is market−oriented technology research to select the highest−priority reservoirs for the development of integrated fisheries. And for each of these reservoirs market, cultural, and economic assessments should be carried out—to identify the best fish, the best system, and the best markets.

Research is also needed on how the management of dam operations can sustain or enhance fisheries. For example, water withdrawals could be timed to stimulate spawning—by discharging enough water to ensure the spawning of riverine fishes downstream during the crucial spawning season—or drawdown could be used to control the spawning of an unwanted species.

Another research need is to establish the minimum water levels necessary to conserve a species. While Fraser (1975) found that 30 percent of the mean annual flow is satisfactory for maintaining salmonid fisheries, such data are lacking for many tropical reservoir fisheries projects. In Tamil Nadu, India, reservoir authorities have agreed to maintain a minimum water level of 10 percent of the full pool level to conserve broodstock and ensure successful spawning (Sreenivasan 1986).

There are many, more specific needs for strategic applied research in integrated reservoir fisheries:

Research is needed to help predict the timing, magnitude, and duration of reservoir turnovers, to develop a simple monitoring system, and to determine whether turnovers are due to surface cooling or to upwellings of bottom waters caused by riverine inflows.

The feasibility of supplementing reservoirs with freshwater pelagic sardines, which occupy the all−too−often empty open waters (the pelagic zone), should be tested. At Ubolratana Reservoir in Thailand the development of a small, pelagic fish helped ensure the food security of the poorest people displaced by the reservoir (Costa−Pierce and Soemarwoto 1990a).

The cost−effectiveness of recurrent stocking of fish in tropical reservoirs should be compared with that of stocking self−perpetuating species. Research should also look at what timing for stocking and what size of stocking fish would maximize survival rates and economic returns in reservoir capture fisheries.

Low−cost pens should be developed to enhance stocks, and artificial spawning sites created to enhance fisheries.

The use and cost−effectiveness of physical mitigation measures (ladders, fishways, diversions) should be examined where there are important fisheries for indigenous migrating fish.

Biological engineering solutions should be developed to ensure that water flows from dams are retained and released at ecologically appropriate times to facilitate the spawning and recruitment of fish in reservoir capture fisheries or to eliminate predatory fish. Research is also needed on the positive and negative effects of drawdowns on reservoir cage aquaculture systems.

Research is needed on the costs and benefits of clearing or not clearing reservoir bottoms in different types of reservoirs with capture fisheries.

Low−cost aquaculture systems should be developed that are more affordable for the poorest displaced residents and that produce fish suitable for meeting nutritional needs and for sale in local markets.

The carrying capacity of semi−intensive and intensive cage aquaculture systems in reservoirs with different water renewal rates should be estimated, to test the hypothesis that reservoirs with higher rates can support more cages. And the carrying capacity of extensive cage aquaculture in organically enriched (eutrophic) reservoirs should be compared with that in organically poor (oligotrophic) reservoirs.

Finally, research is needed to make it possible to conduct fish farming—from hatchery to growout—entirely in floating systems for the many species that now require land−based systems (such as ponds) during some part of their life cycle. Making farming systems entirely floating would relieve pressure on the land surrounding the reservoir and increase the number of productive enterprises that can be located on the reservoir water surface.

The development of integrated fisheries as a means of environmental and social rehabilitation is constrained by the lack of a focal point for solving the many complex and multidisciplinary problems they involve. Establishing a "research reservoir" or a center for research on tropical reservoirs, resettlement, and the environment would allow practical work to be done on the interface between engineering, ecological, social, and technical problems.

Disseminating Information

Closely related to the need for applied research is the need for greater dissemination of information on reservoir fisheries. Much information is buried in fisheries institutions, mainly in unpublished, inhouse, or "grey" literature, although such institutions as ICLARM, the Food and Agriculture Organization, and the Southeast Asia Fisheries Development Center do make some of this information available. Reservoir fisheries literature is rarely collected and disseminated, and little information has been gathered on the social, economic, and institutional aspects of reservoir fisheries. Moreover, there is no regular mechanism in Asia for disseminating information on reservoir fisheries. Only in China, which has a reservoir fisheries research institute and a journal of reservoir research published in Chinese, is the information that is necessary for making integrated technical proposals and policy decisions available in one place.

As a result, for many Asian countries the unrecorded experience with reservoir fisheries far exceeds the written documentation. Much of this experience would be of great value for the growing number of workers who recognize the potential of reservoirs for inland fisheries development in Asia.

Conclusions and Recommendations

The new productive enterprise systems in the Saguling and Cirata Reservoirs have met human needs and have provided local resettlement options far beyond what was envisioned in the original development plans. Involuntary displacement and resettlement typically are associated with serious, long−lasting, adverse effects, but for the communities displaced by Saguling and Cirata that have moved into fisheries, the new reservoirs are the source of restored incomes and successful development. While these successes must be attributed to the people and organizations on the ground, an overall support structure was necessary to provide a push and to ensure completion of the efforts to develop the integrated fisheries ecosystems. The World Bank's funding, monitoring, and supervisory roles were essential. In a time when large dam and reservoir projects are under attack because of their social and environmental impacts, development planners would do well to study carefully the lessons for resettlement offered by cases such as that of Saguling and Cirata.

Key Ingredients for Successful Reservoir Fisheries

How reservoir fisheries develop will vary substantially among projects, depending on the physical, economic, and sociocultural context. Even so, there are a small number of core variables that need to be considered in nearly all fisheries development programs. The success of the reservoir culture fisheries in West Java also depended on four essential conditions in the local area:

Markets and market access—the presence of large, unsaturated markets in a densely populated region where freshwater fish has traditionally been the main source of animal protein, consumer recognition of the product is high, there is good access to capital, and fish marketing and transport infrastructure is excellent.

Inputs—adequate availabilities of seed fish (fingerlings) and feed.

Human capital—farmers' sophisticated traditional knowledge of fish and fisheries systems.

Financing—the ready availability of capital from compensation money and other sources, allowing the displaced people and others to make immediate investments in new fisheries enterprises.

Successful reservoir capture fisheries schemes in Asia use self−perpetuating species with short life cycles that can be heavily fished with low−cost gear and are owned and managed by local people. Successful species in reservoir capture fisheries have been the tilapia (Indonesia, the Philippines, Sri Lanka), freshwater sardines (clupeids) (Thailand), and indigenous carp (India, Sri Lanka). Selective fishing of predators has increased total yields and allowed the manipulation of reservoirs' fish species composition in order to build large populations of herbivorous and omnivorous fish that have contributed substantially toward meeting human needs.

Reservoir aquaculture schemes developed, in their initial phases, low−cost cages appropriate to, and conserving of, available capital. They were then intensified as capital availability and market demand increased. For the poorer segments of society, mini−cage or subsistence systems and no−feed cage culture systems have been successful in Indonesia, Nepal, and the Philippines. For entrepreneurs with more capital, semi−intensive and intensive systems (single and biculture cage systems) have proved profitable.

Dam operations play an important part in the success of reservoir fisheries. The extent and timing of changes in water levels in a reservoir and the size of the minimum pool of water maintained affect the production and yield of both capture and culture fisheries systems.

There is a wide range of cage aquaculture systems. To ensure that the systems selected for development are those where the seed, feed, and need are clearly present, a "market−driven technological approach" is needed.

Recommendations

This review of options for developing reservoir fisheries as a tool in resettlement at the Saguling and Cirata Reservoirs and elsewhere in Asia has led to four main recommendations. First, development planning for integrated fisheries ecosystems to support resettlement and social and environmental rehabilitation should be included in the policy and operational guidelines for all water resource projects in developing countries, especially for damreservoir, irrigation, watershed, and river basin development projects.

Second, hydropower and other water resource development projects should not be explained as a win−lose situation pitting urban interests against rural, and the interests of the rich against those of the poor. Instead, plans for developing integrated land−water ecosystems for social and environmental rehabilitation should be woven into long−term regional development plans. These plans should ensure that people are resettled locally, and given a vision of a better life, with rural roads, electrification, new water−based businesses, and other means for restoring their lives and building productive enterprises. Development planning for integrated fisheries systems should be included in regional development plans wherever World Bank−financed projects affect water resources and ecosystems.

Third, the rehabilitation of natural ecosystems damaged because of water resource development projects, and the adaptation of the displaced population to a new fisheries culture, should be seen as a process and broken down into specific phases, with objective milestones of progress in each phase. To ensure that these milestones are met, an effective monitoring and reporting system should be established. The environmental impact assessments routinely required at the initial stages of hydropower and irrigation projects should be expanded to cover social and resettlement concerns. These assessments should be conducted regularly as part of a continual monitoring process the first 10 years after the impoundment of a reservoir. After that time, the monitoring process could be taken over by universities or NGOs or privatized.

Fourth, where there are major water resource development projects with social and environmental impacts, multidisciplinary river basin commissions need to be formed that include fisheries experts and planners. These commissions should be funded under project loan agreements, remain in operation for a minimum of 10 years after project loan agreements are signed, and be responsible for contributing to the development and management of the fisheries ecosystems approach as part of the monitoring process.

Notes and References

Notes

1. Bernacsek (1984) has reviewed in detail the fundamentals of dam engineering essential for understanding the effects of dams on indigenous fisheries and for developing reservoir capture fisheries.

2. Marshall (1984) performed a similar exercise for African reservoirs.

3. China has an estimated 87,000 reservoirs, with an area for fisheries development of about 1.5 million hectares, about 40 percent of the nation's potential area for inland fisheries. In 1988 reservoirs in China produced an estimated 308,700 tons of fish, for an average yield of 214 kilograms per hectare a year (Liu, Zhitang, and Zegui 1992). Although the technology of cage aquaculture has been evolving rapidly in China, most reservoirs have been developed for capture fisheries for indigenous Chinese carp. Lin, Guggenheim, and CostaPierce (forthcoming) have reviewed the development of Chinese reservoir fisheries in detail.

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