Constraints to the Sustainability of Cage Aquaculture for Resettlement From Hydropower Dams in Asia: An Indonesian Case Study

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From 1985 to 1988, the Saguling and Cirata hydropower reservoirs in the highlands of West Java, Indonesia, displaced more than 40,000 families. As part of a comprehensive resettlement plan, an attempt to resettle 3,000 families in water-based floating fish cage aquaculture and land-based aquaculture support was initiated. Although the reservoir cage aquaculture developments were successful from a fish-production viewpoint, since 1944 cage aquaculture has not been socially or environmentally sustainable. Fish cage aquaculture in reservoirs can be an important new means of population resettlement from hydropower dam construction and protein production in tropical developing countries only with adequate government planning for fisheries; adequate financial compensation for lost assets; rigid enforcement of institutional regulations guaranteeing the long-term benefits of the new lakes for the exclusive use of the displaced people; enforcement of regulations on cage numbers to prevent environmental degradation; and adequate government subsidies for aquaculture job creation, training, long-term extension support, and active monitoring.

Due to increased demands for reliable supplies of electric power, irrigation, and drinking water, the number of new hydropower reservoirs is increasing dramatically, especially in Asia. According to the last report of the International Commission on Large Dams, the total number of dams on earth grew from about 5,000 in 1950 to more than 40,000 in 1986, with China the home to about 50% of these (McCully, 1996).

Dams continue to be one of the only means to increase humanity's access to more of the earth's runoff for new cities and expansion of irrigated agriculture, but they are increasingly expensive socially, environmentally, and economically (Postel, Daily, & Ehrlich, 1996). For example, in arid, rapidly urbanizing southern California, the new Eastside Reservoir will flood only 1,800 ha but will cost some $2 billion. In addition, there is a trend toward construction of larger dams having greater combined costs. Construction of dams with elevations greater than 100 m rose by 27% between 1991 and 1993. More than half of these dams were in China, India, and Turkey (Gardner & Perry, 1995). Large hydropower reservoirs have caused massive social disruption, increased incidences of water-borne diseases, erosion, and other social and environmental degradation (Cernea, 1988, 1997; Hunter, Rey, & Scott, 1983; Lelek, 1984; McCully, 1996; Petr, 1978) (see Figure 1).

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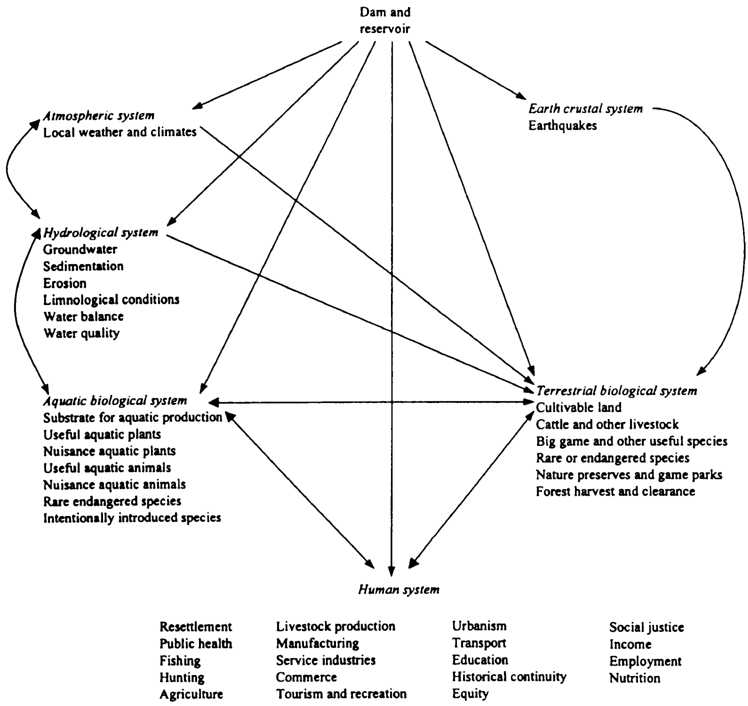

Figure 1: Social and Environmental Impacts of Hydropower Development on a Tropical Watershed and Landscape Ecosystem
Source: Costa-Pierce (1997).

There is a need to develop new, more sustainable environmental planning and policy approaches that integrate social and ecological concerns in hydropower projects worldwide. These social ecological approaches would formulate and carry out long-term rehabilitation efforts with rural societies to restore damaged aquatic environments from hydropower projects. New approaches are especially needed in densely populated areas of Asia where the pace of dam construction is accelerating (Alam, Mirza, & Maughan, 1995; Cernea, 1997; Costa-Pierce, 1997; Sutandar, Costa-Pierce, Iskandar, Rusydi, & Hadikusumah, 1990).

It has been estimated that annual inland fish production in Asia is 5.5 million tons, composing 57% of the world's inland fish production (De Silva, 1988, 1992). However, fish yields from Asian reservoirs compose just 0.5 million tons of this 5.5 million tons (De Silva, 1988). De Silva (1988) estimated fish production from Asian reservoirs at only 20 kg/ha/year, with a wide variability in production that was not always related to the size of the reservoir. Costa-Pierce and Soemarwoto (1987) calculated an average percentage increase in reservoir area in 15 Asian nations from 1987 to 2000 would be 511%, ranging from 50% (Singapore) to 9,900% (Laos). By 2000, it is predicted that the collective water surface in reservoirs (20.3 million ha) will exceed the surface area of Asia's natural waters (18.5 million ha). Clearly, if the huge expanse of underused water areas locked behind Asia's dams could be used for increased fish production, thousands of tons of new aquatic protein could enter Asian markets. Production of new aquatic protein is especially urgent in Asia, which is a region where fish is the most important source of animal protein. In addition, there is an evident need to create thousands of new rural jobs due to population growth and to find innovative ways to stem the rapid rural to urban migration. It is argued that expansion of aquatic food production in Asian reservoirs could assist in mitigating Asia's growing food and population crises (Brown, 1997).

The planned development, enhancement, and management of capture (*fishing*) and culture fisheries (*aquaculture*) enterprises in new reservoirs as alternative livelihoods for the people displaced by dam construction has received little or no attention. The incorporation of fisheries into the planning for dams and the technical, social, environmental, and economic benefits of fisheries to dams projects have not been done. Fisheries has not been incorporated into the social and environmental compensation packages of hydropower dam projects (Cernea, 1997). Hydropower projects are usually controlled by dam engineers and government officials more concerned with moving people away from the new water bodies than promoting new forms of intimate contact with them (such as the Indonesian transmigration projects) (Fearnside, 1997). An alternative view is to develop policies and planning structures to resettle the displaced people locally and encourage development and evolution of new, community-based, social-cultural interactions with the new aquatic ecosystems to rehabilitate the damaged social and environmental situations. The evolution of sustainable, ecological aquaculture holds this kind of rehabilitation potential (Costa-Pierce, in press).

Most of the world's current population growth is occurring in nations where there is little potential for increasing the area of arable land under cultivation (Brown, 1997; Engleman & LeRoy, 1995; Pimental et al., 1997). States Engleman (1995), "The food that will be required to feed a world population of 8 billion or more in the next century will have to come almost entirely from today's farmland" (p. 112). The rapid rate of urbanization in most Asian nations is causing severe population pressure on existing rural and peri-urban agricultural ecosystems. Java is one of the most densely populated areas of the world, and the island is losing agricultural lands to urbanization at an alarming rate. Between 1983 and 1992, new housing starts in just three cities in West Java (Bekasi, Bogor, Tangerang) ate up 61,000 ha of croplands (Firman &

Dharmapatni, 1995). The U.S. Department of Agriculture estimated that urban expansion claimed 20,000 ha on Java in 1994 alone (Thompson, 1995). Rapid urbanization has increased the need to preserve and intensify agricultural production on the remaining agricultural areas and to find innovative ways to conduct intensification sustainably without further environmental and social damage.

Densely populated Java and southern China have been two ancient centers of farmer innovations that have numerous sustainable examples of productive, ecologically sophisticated backyard and small farm ecosystems that merge agriculture and aquaculture in unique ways (De la Cruz, Lightfoot, Costa-Pierce, Carangal, & Bimbao, 1992; Koesoemadinata & Costa-Pierce, 1992; Ruddle & Zhong, 1988). However, due to urbanization and associated population pressures, the era of consistent increases in the numbers of these sophisticated traditional aquaculture agroecosystems in Asia may be coming to a close, principally due to their land-intensive nature and their proximity to the main areas of urban sprawl. In the peri-urban fringes of many large Asian megacities (Jakarta, Bangkok, Manila, etc.), there is an alarming loss of these traditional agroecosystems and the indigenous knowledge systems that have developed throughout hundreds of years to manage them.

In contrast, there are vast areas of new inland waters locked up in hydropower and irrigation reservoirs in the region. The surface waters of these hydropower reservoirs are almost completely vacant of any significant productive enterprise other than being used for water storage and subsistence level fishing that provides little other than part-time incomes (Munro, Iskandar, & Costa-Pierce, 1990). Nearly all Asian reservoirs outside of China and Thailand have little or no water-based aquaculture systems, such as fish cages, and have underdeveloped capture fisheries management programs (Costa-Pierce, 1997; De Silva, 1988, 1992). Development of aquaculture in and around Asia's hydropower and irrigation reservoirs to enhance fish production and as a management tool to enhance capture fisheries may be one means to provide thousands of new jobs in rural areas. Fisheries development may also be the only means left for creating new sources of freshwater aquatic protein for many densely populated Asian nations (Costa-Pierce, 1997; De Silva, 1988). Indeed, hydropower and irrigation reservoirs may be Asia's final aquatic frontier.

The Case Study of Resettlement Aquaculture in Indonesia

A cooperative Institute of Ecology (IOE), Padjadjaran University (Bandung, Indonesia), and International Center for Living Aquatic Resources Management (ICLARM, Manila, Philippines) project in the highlands of West Java, Indonesia, was initiated to investigate the feasibility of developing cage aquaculture for local population resettlement from hydropower dam construction. Indonesia was chosen for the project due to the need to evolve alternative resettlement schemes to the transmigration program that had caused some social and environmental problems and was costly (Fearnside, 1997). The use of floating cage aquaculture (FCA) to resettle 3,000 of the 40,000 displaced families locally was proposed because FCA was deemed compatible with engineering forecasts of dam operations and drawdowns (Costa-Pierce & Soemarwoto, 1990). The purpose of this article is to describe the initial institutional framework, planning, and policy efforts and the extension and training programs conducted during the project and to discuss the reasons for project success, failures, and long-term constraints to environmental and social sustainability in light of the possible transfer of this model to other (especially Asian) nations with similar aquatic resources and social and economic development scenarios. Details of the project's technical, aquaculture, fisheries, and economic aspects have been reported elsewhere extensively (Costa-Pierce, 1997; Costa-Pierce & Soemarwoto, 1990; Sutandar et al., 1990) and will be mentioned herein only for their relevance to the discussion of social, institutional, and environmental sustainability and transfer of technologies.

Institutional Framework and Planning Process

Funding for the resettlement aquaculture efforts was obtained from the World Bank as a small portion of a larger loan package to the Indonesian State Electric Company (PLN) for dam construction at Cirata. The aquaculture development portion of the World Bank loan was divided into local (Rp 917,441,530) and foreign currency (U.S. $416,690) components and administered by IOE (local) and ICLARM (foreign) agencies for project implementation (at project initiation in January 1986, U.S. $1 = 1,130 Indonesian Rp [IDR]; in September 1986, the IDR was devalued to 1,640 Rp).

The primary objectives of the project were to provide (a) *technical support*, defined as applied ecological, capture fisheries, aquaculture research, extension, training, and other support services to the West Java Provincial Fisheries Agency (Bandung, Indonesia) to facilitate rapid resettlement of 3,000 families in either full- or part-time jobs in reservoir aquaculture, capture fisheries, or related support industries in the two hydropower reservoir areas: the Saguling reservoir (1,500 families) and Cirata (1,500 families) reservoir areas; and (b) *planning*, that is, a comprehensive reservoir fisheries and aquaculture development and management plan for population resettlement.

Despite the relatively large information base available in freshwater aquaculture development and capture fisheries management in Asia, there were no previous experiences anywhere involving the resettlement of such a large number of persons through a planned development program of reservoir cage aquaculture and its allied land-based aquaculture support systems (such as hatcheries and nurseries). For this reason, the World Bank suggested that IOE associate with an international fisheries research organization (ICLARM) to assist with technical advice in fisheries and project implementation.

A new institutional framework had to be formulated for project implementation because loan documents were inadequate in defining an overall administrative structure for the project and in delegating individual institutional responsibilities. The IOE was chosen as the lead agency to coordinate a multidisciplinary applied research and training program that involved agricultural economists, sociologists, demographers, anthropologists, agronomists, forestry, animal husbandry, capture fisheries, and aquaculture professionals. To assist IOE's applied research program, ICLARM provided the services of a full-time resident consultant fisheries scientist. ICLARM also provided specific short-term scientific expertise in capture fisheries, aquaculture, and fisheries marketing and economics. The Indonesian government's West Java Provincial Fisheries Agency created a special reservoir fisheries technical implementation unit that established offices at both the Saguling and Cirata dam sites to lead the local extension and training efforts. IOE also hired fisheries extension personnel on 3-year contracts to facilitate more rapid transfer of applied research results to villagers and to coordinate extension activities with the government's technical implementation unit. The PLN provided funding, institutional coordination, and unlimited access to the reservoir areas for research and development activities because, after compensation monies were paid, the reservoirs and their drawdown areas were PLN's private property.

On delegation of responsibilities, a planning process was undertaken by IOE and ICLARM to apportion the large workload into teams to implement the diverse number of applied research activities to be conducted with the displaced people (see Table 1). Geographic areas where applied research was to be conducted were chosen in new or expanded villages having the largest numbers of displaced residents (taken from the electric company's compensation reports).

Applied research was done in a participatory manner with villagers in capture fisheries, aquaculture, drawdown agriculture, sociology, fisheries economics, and marketing. A number of different types of low-cost, water-based, cage aquaculture systems were developed and tested (Costa-Pierce & Hadikusumah, 1990, 1995). Fish cage capital costs ranged from Rp 491,000 (U.S. $299) for cages having recycled oil drums and wood frames for flotation to Rp 177,500-274,500 (U.S. $108-$167) for

Table 1

Planning Process Used to Complete an Implementation Plan for Applied Research in Integrated Reservoir Fisheries and Aquaculture Development

Step 1

Synthesis of project agreements and goals
Formal and informal meetings with cooperating agencies
Assignment of project staff into three subprograms:
- Aquaculture development
- Capture fisheries development and management
- Socioculture, economics, and marketing

Step 2

Preliminary surveys and data gathering in three subprogram areas of the project

1. Aquaculture development
   - Information on existing traditional and modern systems and knowledge base; production; feeds and feeding practices; systems design, economics, organization, and interactions; constraints; past performance; species; rationales for use; labor use; and success/failures
   - Secondary data from national, provincial, regional, city, village fisheries institutions, universities, and private operators regarding specific systems likely to be of use in reservoirs
   - Interviews with farmers and middlemen, trips to markets, infrastructure, daily/weekly routines, problems with materials and labor, environment, technology, and neighbor relations
2. Capture fisheries development and management
   - Broad environmental surveys of fisheries ecosystems and changes occurring in it, ports/harbors, industrial developments, value-added products, and postharvest traditional techniques
   - Main hydromorphometric biological, limnological, and climatological factors;
   - Information on past/present fishing efforts, species, yields, gear used, catch per unit efforts, labor, routines, and transportation costs/patterns
   - Fishermen's impression of new environments and effects on new ecosystems from demographic, local, polluting, market, and political changes
3. Sociocultural economics and marketing
   - Data on population sizes, income, fish consumption patterns, forms/sizes of fish eaten, cultural reactions to fish products, land-use patterns, agricultural interfaces, land tenure, and rapid rural appraisals
   - Adaptations to new reservoirs, special environment/people interactions, resource use patterns, and exploitation/mining activities
   - Constraints and limiting factors to resource use and conservation
   - Availability of funds; knowledge of loans, credit; use of banks; familiarity with the concepts of loans/credit

(continued)

Table 1 Continued

Step 2	
	3. Sociocultural economics and marketing Analyses of fish markets, market structures, distribution and transportation systems, marketing costs, middlemen, market supply statistics from all administrative levels, market price fluctuations with peak supply, and market capability projections
Step 3	
	Summary report on findings in each subprogram area in chapters comprising draft implementation plans for the following: Aquaculture development Capture fisheries development and management Sociocultural economics and marketing
Step 4	
	Complete synthesis of three subprogram plans for a single implementation plan through development Implementation plan is subject seminar of invited experts and is revised according to changes and recommendations Final implementation plan for fisheries and aquaculture development as a means of large-scale resettlement

cages having bamboo or banana logs for flotation. Low cost "mini" cages (17.3 m3) were also developed that cost between U.S. $20 and $70 to construct (Costa-Pierce & Hadikusumah, 1990). In addition, a suite of low-cost land-based hatchery and nursery aquaculture systems were developed. In contrast to the report of Zerner (1992), aquaculture systems developed were simple and not elaborate and were well within the financial means of the majority of the displaced people (Costa-Pierce & Hadikusumah, 1990; Rusydi & Lampe, 1990).

Technological interventions in land-based aquaculture were based on existing models of traditional knowledge systems in integrated agriculture-aquaculture farming ecosystems present for more than 100 years in West Java (Djajadiredja, Jangkaru, & Junus, 1980; Thornburn, 1982). Cage aquaculture technologies were based on previous Indonesian and overseas experiences (Costa-Pierce, Bimbao, Zainal, & Effendi, 1989; Costa-Pierce, Rusydi, Safari, & Wira Atmadja, 1989a, 1989b, 1989c; Costa-Pierce, Wira Atmadja, Rusydi, & Safari, 1989; Costa-Pierce, Zainal, & Effendi, 1988; Gonzales, 1984; Hai & Zweig, 1987; Pullin, 1986; Rifai, 1985). Development of the land-based and water-based aquaculture systems was integrated in an attempt to combine the new, water-based reservoir cage systems into an existing social ecological system of traditional pond hatchery and rice-fish nursery systems, thereby creating as many new jobs as possible by using aquaculture's "multiplier effects" (Costa-Pierce, 1992, p. 39; see also Costa-Pierce, 1997; Koesoemadinata & Costa-Pierce, 1992).

Farming Systems Extension and Training Programs

Two extension approaches were used to disseminate aquaculture technologies to displaced persons. For new "water farmers" totally unfamiliar with traditional aquaculture technologies in West Java, adoption/diffusion techniques (Pollnac, 1982) were chosen. For farmers who knew about traditional cage aquaculture or land-based aquaculture techniques, a farming systems research and extension approach was used (Chambers, Pacey, & Thrupp, 1989). This division of extension efforts was not a hard and fast categorization, however. It was left up to farmers themselves to choose which training sessions they wanted to attend. Many farmers attended sessions using both extension techniques.

Traditional Training Methods

In 1982, 3 years before the first reservoir was to be flooded (Saguling was flooded in 1985-1986), formal classroom and hands-on training in cage aquaculture was conducted with a small group of selected residents (mostly village leaders) who were to be displaced. Hands-on practical training in cage aquaculture was conducted in a small, shallow lake in Bogor (Lake Lido) and in an existing, downstream reservoir (Jatiluhur, Indonesia). In addition, a special fisheries dike area was created by the State Electric Company in the Saguling Reservoir for cage aquaculture experiments before the flooding of the main part of the reservoir (Rifai, 1985). Aquaculture training was conducted for 24 displaced persons by the Research Institute for Freshwater Fisheries in Bogor and the Department of Fisheries in Padjadjaran University in this diked area. Two displaced farmers from this latter group subsequently received loans from the Bank of Indonesia to develop cage aquaculture businesses after initial experimental results showed the potential for high yields and profits (Rifai, 1985).

The two pioneer farmers successfully paid back loans from the Bank of Indonesia by the 2nd year of operation. Their positive results attracted a great deal of community interest. At the same time, the State Electric Company facilitated a highly publicized visit by the governor of West Java to these two farmers. These preinundation events created a widespread awareness of the potential of cage aquaculture among Saguling's displaced people, and the two successful farmers later became *kader-kader petani ikan* (fish farmer facilitators).

Further experimental work from 1986 to 1990 developed a basket of low cost technologies in cage aquaculture, small-scale ("backyard") fish hatcheries, water-based hatcheries, and integrated rice-fish nursery systems appropriate to the rural expertise, availability of capital and construction materials, and management complexity of displaced farmers (Costa-Pierce, 1992, 1997; Costa-Pierce & Hadikusumah, 1990, 1995). All research employed displaced villagers (the beneficiaries for whom the technologies were intended) who worked with scientists from the outset. Simultaneously, the West Java Provincial Fisheries Agency and IOE/ICLARM collaborated to offer a number of short courses of 1 week to 3 months duration for villagers at offices of village headmen. These courses were held in more than 20 districts in the Cirata region and were attended by more than 500 persons. Courses covered operations of numerous types of land and water-based aquaculture systems having high and low capital costs (e.g. intensive raceway systems, hatcheries, small and large cages, pen systems, rice-fish culture) in addition to instruction regarding how to formulate fish feeds and process and market fish (see Table 2).

Fish Farmers' Association (FFAs)

A Saguling Fish Farmers' Association (SFFA) was formed in late 1985 and by the end of 1989 had more than 700 members. Leadership of the SFFA was by the two pioneers who successfully repaid their loans (subsequently, these two and their families became the most powerful members of the fish farming community). The SFFA was formed by the Technical Implementation Unit of the West Java Provincial Fisheries Agency who also assisted farmers with obtaining bank loans and marketing fish.

In Cirata, a government Village Cooperative Unit (Korporasi Unit Desa, or KUD) took the lead in cage aquaculture development with assistance from the government's Technical Implementation Unit. In 1989, the cooperative obtained a government loan package in excess of Rp 100 million to develop cage aquaculture in Cirata.

Farmer Participatory Training Methods

A farming systems research and extension approach was chosen because it was known that West Java had a unique cultural heritage and a large bank of traditional knowledge in many areas of land and water-

Table 2
Subject Areas Covered in Formal Aquaculture Training Courses Offered by the Aquaculture Resettlement Project in Impacted Villages

Aquaculture Systems	*Subject Areas*
Hatcheries	Site selection
	Designs and construction
	Broodstock selection, management, and feeds/ feeding
	Spawning, egg collectors
	Nursery pond management
	Water quality and natural feeds management
	Harvesting, economics, marketing, security
Small bamboo cages; floating net cages	Site selection
	Designs and construction
	Aquaculture species production
	Aquaculture management; seed management, feeds, feeding
	Diseases
	Harvesting, economics, marketing
Pen systems	Community organization, group process training
	Site selection
	Design and construction
	Seeding and fertilization
	Compost as feeds and fertilizers
	Harvesting methods
	Marketing and security
Rice-fish culture	Design and trench types
	System types and sizes
	Water quality and management
	Feeding and fertilization
	Integration with rice schedules
	Integrated pest management
	Harvesting methods
	Economics, marketing and security
Running water systems	Site selection
	Designs and construction
	Water quality and management
	Aquaculture species production
	Aquaculture management
	Harvesting, economics, marketing, security
Fish feeds processing	Feeds available, their composition and costs
	Raw materials available
	Low cost processing methods
	Economics and marketing
Postharvest fish processing	Traditional methods, techniques and materials
	Modified low cost methods
	Storage, marketing and economics

based aquaculture and integrated farming systems (for examples see Costa-Pierce & Effendi, 1988; Djajadiredja et al., 1980; Little & Muir, 1987; Thornburn, 1982). Many traditional aquaculture systems and much of the existing farmers' knowledge could be used directly or modified and adapted for use.

It was decided that all adaptive research should employ the villagers from the outset and that the villagers would be involved throughout the success or failures of the aquaculture research, development, and adaptation processes. Using this approach, farmer recipients were made active, valued participants in both the process and evaluation of the suitability of chosen technologies for their needs. There was a high level of indigenous, aquaculture farming knowledge in the rural society where the development project was undertaken. Surveys before the project began documented that a wide diversity of aquaculture systems already existed, that farmers in the surrounding region had an impressive management capability, and that farmers were already doing detailed practical experiments (Koesoemadinata & Costa-Pierce, 1992). In the design of the efforts, project scientists realized that it was best if the scientists recognized these farmers and their indigenous knowledge for the value of their innovations, because this approach would speed the choice of more promising and relevant research topics of direct value to the intended beneficiaries. Lightfoot (1987) has also pointed to the unique value of indigenous research to setting the research agenda of both on- and off-station research workers.

Three cage aquaculture research stations were constructed to test a variety of low-cost technologies (the so-called basket) under three different but prevailing limnological and social/cultural conditions in Saguling in the years just after reservoir filling (the on-station experimentation phase).

Establishment of Community Integrated Aquaculture Schools

Although development of the aquaculture resettlement option was the main concern of the project, it was clear from the outset that a more holistic approach to applied research, extension, and environmental restoration would be necessary. To accomplish this, community schools (called *Pusat Penelitian Sistem Terintegrasi Tanaman, Ternak dan Ikan,* or Research Centers for the Integrated System of Plants, Farms Animals, and Fish) were created in three villages surrounding the Saguling reservoir with the largest percentage of displaced residents.

The project rented village houses for a 3-year period in two villages in Saguling's northern region (Cangkorah and Cipondoh villages) and one in the southern region (Awilarangan village) in areas having excellent technical capabilities for cage aquaculture and boat and road access to markets. Another house was rented in Mande village to coordinate applied research and community training activities in Cirata.

Village schools had a permanent IOE/ICLARM staff member stationed at the houses who coordinated all applied research projects, hands-on training, and community relationships. Villagers were employed to carry out all aquaculture construction, labor, and routine tasks at the schools. Village schools were the center of all collaborative research activities with villagers and between the various outside institutions and other outside villagers visiting the schools. Village schools were visited regularly on overnight stays by IOE, ICLARM, and Provincial and Technical Unit personnel to mentor progress, discuss results internally, and to meet and discuss progress with villagers.

Village schools were replete with displays, photographs, and extension aquaculture books written in both the local and national languages (Costa-Pierce et al., 1989a, 1989b, 1989c; Costa-Pierce, Bimbao, et al., 1989; Costa-Pierce, Wira Atmadja, et al., 1989). Programs at the village schools focused not only on aquaculture but also had working demonstrations in animal husbandry, composting, soil conservation, capture fisheries, fish feed formulation, and fish processing technologies. The village schools also promoted an environmental rehabilitation system that took a system ecology approach to small-farm development. Many ecological principles were intuitively familiar to the sophisticated rural farmers, but scientific staff also introduced them to a wide range of new technologies (cage aquaculture, land-based aquaculture systems such as hatcheries and new rice-fish systems), rabbit husbandry, earthworm culture and composting, insect culture, fish and animal processing and marketing, and agroforestry and erosion control (Maskana, Astuti, Sudiarto, & Soemarwoto, 1990).

It was estimated from records kept at the schools that more than 4,000 villagers visited the four village schools from 1986 to 1990.

Farmer-to-Farmer Visits

Once the Saguling cage culture industry began its remarkable expansion, the task of attracting new entrants was of little concern for the project. Indeed, control of the number of cages became an issue as early as 1989 when cages became concentrated in one of the southern sectors of Saguling reservoir (Bongas region). By the end of 1989, more than 80% of the cage aquaculturists in Saguling were concentrated in this region (Rusydi & Lampe, 1990). The Bongas region had excellent technical capability for cage aquaculture (a long, deep, sheltered bay with good flushing), good economic infrastructure, and excellent market access to fish fingerling and feed suppliers. Given the obvious success of cage aquaculture development in Saguling, by mid-1988 project extension efforts shifted to the new Cirata reservoir.

Because diffusion of innovations can occur as rapidly with informal farmer contacts as in formal courses in familiar cultural settings (Kang & Song, 1984), a hands-off extension approach was used to develop aquaculture in Cirata. Simple farmer-to-farmer visits were sponsored for displaced residents from the new Cirata reservoir. In structured visits, prospective water farmers from the Cirata reservoir region were sponsored to visit the aquaculturally developed regions of the Saguling reservoir. Extension personnel were present to answer questions, to distribute free aquaculture workbooks in the local language, to provide "social lubrication," and to take care of personal needs. These visits were a tremendous success. By the end of 1989, 94 cages (40 families) were operating in Cirata with no formal course work or extension programs having been conducted. By the end of 1992, fish production in Cirata was estimated at 3,880 tons (see Table 3).

Information Resources

It was found that Saguling's cage fish farmers were well-educated, with 94% having completed elementary school (Rusydi & Lampe, 1990). Almost all of the people could read extension workbooks if they were in the local Sundanese language. Far fewer villagers could read extension materials in the national language (Bahasa Indonesia), and almost no one could read English. As a result, simple comic-book–type workbooks on floating net cages, pens, small-scale hatcheries, and small cages were published in the local Sundanese dialect and distributed widely (Costa-Pierce, Rusydi, et al., 1989a, 1989b, 1989c; Costa-Pierce, Wira Atmadja, et al., 1989; Costa-Pierce, Bimbao, et al., 1989).

Workbooks were made available free at all IOE/ICLARM community schools and at the offices of the government's Technical Implementation Unit at the reservoir dam sites. Books were used widely by extension officers and trainers in formal courses in villages. Workbooks were also available free to all members of the Saguling Fish Farmers' Association and Village Cooperative Units in Cirata.

During visits to cage culture operators in Saguling and Cirata in 1989 to 1990, it was frequently observed that these workbooks were among the only reading materials available in village residences. Children seemed to particularly value the comic-book nature of the materials to the point that cage culture toys appeared in one village.

Table 3
Fish Production in the Saguling and Cirata Reservoirs From 1985 to 1997

Year	*Saguling Cages*	*Saguling Production* (t)	*Cirata Cages*	*Cirata Production* (t)	*Total Production* (t)
1985	0	0	0	0	0
1986	NA	522	0	0	522
1987	NA	1,443	0	0	1,443
1988	765	2,043	NA	26	2,069
1989	1,250	2,204	94	458	2,662
1990	1,365	2,490	361	798	3,288
1991	1,724	2,926	1,043	2,241	5,167
1992	1,846	4,053	1,723	3,880	7,933
1993	2,219	6,666	2,091	6,556	13,222
1994	4,250	6,039	3,860	11,383	17,877
1995	4,425	4,420	7,485	14,644	19,064
1996	NA	4,405	NA	20,091	24,496
1997	8,199	NA	25,558	NA	NA

Note: Saguling was filled in 1985 to 1986, and Cirata was filled in 1986 to 1987. NA = not available due to a year when no surveys were done or because the data are forthcoming.

Study Tours to Nations with Relevant Experiences

Many aquaculture technologies successful in one developing nation can be transferred to other nations with similar development circumstances after adaptive research is undertaken (World Bank, 1982). However, West Java has a unique aquaculture history, a wealth of experience, and capable fisheries institutions and scientists involved in aquaculture of common carp and other species (Costa-Pierce & Hadikusumah, 1990). However, the following was noted:

1. Saguling and Cirata were very eutrophic reservoirs with a large potential for "no feed" or extensive cage aquaculture.
2. Much of the specific technology to diversify the reservoir cage culture industry and assist the poorest of displaced residents (e.g., by evolving a low-cost or extensive cage aquaculture, particularly for Nile tilapia [*Oreochromis niloticus*] and Chinese silver [*Hypophthalmichthys molitrix*] and bighead [*Aristichthys nobilis*] carps) was lacking.

It was felt by project scientists that transfer of modern methods and management practices in extensive aquaculture to the Indonesian reservoirs would not be a prolonged proposition or expensive exercise. The

Philippines has a wide diversity of successful tilapia cage and pen aquaculture, and extensive cage aquaculture for the Chinese carp has been successful in lakes in China, Nepal, and Singapore (Chookajorn, 1982; Gonzales, 1984; Guerrero, 1982; Hai & Zweig, 1987; Pullin, 1986).

It was decided to arrange two study tours in 1987 to 1988 for selected scientists from the PLN, IOE, and the Technical Implementation Unit to transfer technology rapidly from Asian nations with relevant experiences in low-cost cage aquaculture to Indonesia (Costa-Pierce et al., 1988; Costa-Pierce, Bimbao, et al., 1989).

This transfer of technology by sponsoring overseas study tours was very successful. By the end of 1989, 26 small-scale cage hatcheries for an Indonesian variety of red tilapia (hybrids of *Oreochromis* spp.) were being operated by resource-poor farmers in Saguling. Two tilapia growout operations started in 1989 to 1990. In addition, in 1990 a number of cage operators started doing polycultures of common carp and red tilapia in cages. Active research in tilapia aquaculture was started by the Provincial Fisheries Agency at the local university (Department of Fisheries, Padjadjaran University) and at IOE.

Short-Term Analysis of Successes and Failures (1986-1993)

Aquaculture as a means of sustainable rural development in developing nations has been sharply criticized by a number of authors (Costa-Pierce, 1996; Folke, Kautsky, & Troell, 1994; Kautsky, Berg, Folke, Larsson, & Troell, 1997; Zerner, 1992) and, in general, remains an elusive goal. The main problems have been insufficient attention to realistic economic appraisals; a lack of social concerns, especially social impacts on equity; a lack of expertise; and a lack appropriate technologies incorporating traditional knowledge (Pollnac & Sihombig, 1996).

The reservoir aquaculture resettlement project was successful in a technical sense in developing numerous new land and water-based aquaculture systems and associated aquaculture support industries in villages surrounding the two new hydropower reservoirs (Costa-Pierce, 1997; Costa-Pierce & Soemarwoto, 1990; IOE & ICLARM, 1989; Sutandar et al., 1990). The project trained a documented 2,081 persons and recorded more than 4,000 visits to village schools; by 1992, an estimated 7,527 persons were directly or indirectly involved in fish production; and at the end of 1996, total annual fish production from cages from the two reservoirs was an amazing 24,496 tons.

It is important to reflect a little on the magnitude of this production. The reported range of capture fisheries production in southeast Asian reservoirs is just 5 to 675 kg/ha/year (De Silva, 1988). In 1996, cage aquaculture in the Saguling and Cirata reservoirs produced 2,130 kg/ha/year (24,496/11,500 ha), and expansion of production is possible with existing technology and better siting. Costa-Pierce and Hadikusumah (1990) demonstrated that each cage could produce fish at 3 tons/year if adequate supplies of fingerlings were available. Applied across the 16,400 cages (at carrying capacity), this would yield 49,200 tons of fish and generate an estimated U.S. $49.2 million per year ($1 per kg) at capacity. The production potential of simple cage systems does not stop there. Costa-Pierce (1997) noted the proliferation of a new type of "condominium" cage aquaculture system in the Bongas area of the Saguling reservoir that had a production potential of 10 tons per cage per year. Clearly, the cage aquaculture systems in the Saguling and Cirata reservoirs present an exciting new model of large-scale protein food production for a protein-hungry Asia that, if sustainable, could represent a new globally important food resource ecosystem.

The most important factors contributing to the initial technical success of the development efforts in the first 7 years were the following:

1. *Presence of a defined, educated target group.* Lists of names with addresses of displaced persons from reservoir inundation were obtained from the electric company along with how much compensation these people obtained. Whereas in many cases the electric company lists were found to be outdated or wrong, the fact that some information did exist helped to identify (a) the exact geographic scope of the project (new and old villages with largest numbers of displaced families) and (b) families who had backyard fish ponds before the reservoir and therefore had a traditional knowledge of aquaculture ecosystems.

2. *Ready availability of investment capital.* Lack of the ready availability of start-up capital often constrains aquaculture development among the rural poor (the target group of many development assistance projects). All villagers in Saguling obtained compensation money from the electric company; 92% received less than Rp 6 million and 8% received more than Rp 6 million (Suwartapradja & Achmad, 1990). Having a large amount of cash available allowed immediate investment in new aquaculture businesses. However, for the poorest residents, compensation was not enough to replace homes and lands lost due to increased land prices, speculation, and inflation (Cernea, 1997).

3. *Lack of alternative employment opportunities in both rural agricultural and human ecosystems.* Rural population densities increased 2 to 3 times due to the reservoirs from a range of 237 to 1,691 persons/km^2 before the reservoir to 476 to 4,292 persons/km^2 after (Suwartapradja & Achmad, 1990). These are among the highest rural population densities anywhere in the world. According to Collier, Hadikoesworo, and Saropie (1977), by the late 1970s the rice agroecosystem in Java could not absorb more rural labor. They predicted massive migration to coastal Javanese cities if a solution was not found (and one was not; Jakarta boomed from 11.9 to 17.1 million in the 1980s).

4. Local traditional knowledge of aquaculture and cage culture. Dahlman and Westphal (1981) describe the success of development assistance in terms of the "technological mastery" of a system, which they define as "the autonomous ability to identify, select, and generate technological improvements and changes" (p. 22). Rapid adoption of the fish cage systems in the reservoirs was influenced by the inherent innovativeness of farmers in West Java. Farmers operating existing agro- and aquaecosystems in the province had an impressive amount of indigenous knowledge and vibrant on-farm "trial and error research" systems that were characterized by a great deal of individual innovation. Fliegel (1984) also viewed the adoption of change as being directly influenced by the basal level of innovativeness present in a society.

5. Large market demands and relatively high prices for freshwater fish. Ikan mas (common carp) are the most preferred fish in West Java. Common carp play a unique cultural role as food eaten at important celebrations (weddings, graduations, family reunions, etc.) among the dominant Sundanese culture in the province. The price for the fish is therefore higher than other fish such as tilapia. Kusnadi and Lampe (1990) observed that price fluctuations for common carp in Jakarta were small even though strong seasonal fluctuations in fish supplies occurred, indicating a large demand exists for the fish. Given the increasing population density and increasing incomes of Jakarta residents (who eat about 14 kg of fish per capita per year), market demands for freshwater fish were large and unsaturated.

6. Ready access to large urban markets on paved roads.

7. Suitable environment. Saguling had many deep, sheltered bays very suitable for cage aquaculture (Costa-Pierce, 1997; IOE & ICLARM, 1989; Soemarwoto, Roem, Herawti, & Costa-Pierce, 1990).

8. Institutional and international cooperation. Although difficult to coordinate and necessitating a larger than anticipated administrative load, the cooperation and technical assistance of international (ICLARM), government, electric company, university ecology, and local fisheries organizations was critical. Having an international reservoir fisheries expert on site for 3 years was also beneficial.

9. Accessibility of rural extension services. Rusydi and Lampe (1990) report that 90% of Saguling's cage culturists with a single fish cage participated in extension and training programs and that 44% of all cage farmers got information from training or extension programs.

Problems and Lack of Sustainability of the Aquaculture Resettlement Option (1994-present)

The main problems experienced in the course of this project were as follows:

Table 4

Numbers of Resettled or Outsider Families Operating Fish Cages in the Cirata Reservoir at the End of 1996

	2 to 4 Cages		*5 to 8 Cages*		*9 to 12 Cages*		*More Than 13 Cages*		*Total of Families*		
Village	*R*	*N*	*R*	*N*	*R*	*N*	*R*	*N*	*R*	*N*	*Total Cages*
1 Cipicung	38	18	50	30	45	26	29	44	162	118	3,105
2 Tegal datar	67	22	112	41	87	42	82	42	348	147	5,190
3 Patok beusi	11	4	15	29	10	34	10	34	46	101	1,682
4 Ciputri	19	14	24	32	10	30	14	31	67	107	1,653
5 Janggari	22	9	33	23	10	16	9	11	74	59	1,054
6 Nyalempet	30	31	61	83	48	78	56	121	195	313	5,946
7 Neundeut	8	27	17	46	6	21	9	17	40	111	1,272
8 Kebon coklat	8	12	24	32	14	30	12	23	58	97	1,546
9 Bongas	21	17	23	27	20	18	9	12	73	74	1,227
10 Calincing	25	22	48	43	37	35	28	44	138	144	2,883
											25,558
Total families	249	176	407	386	287	330	258	379	1,201	1,271	

Source: Data from the West Java Provincial Fisheries Service (1996).

Note: Number in boldface indicates the sum of total cages. R = resettled families that lost land flooded by reservoir impoundment; N = newcomer immigrants from outside reservoir shoreline.

1. *Resources for whom? The problem of equity.* When the cage aquaculture industry began to take off, rich people from the urban centers of Bandung/Jakarta began to enter the industry. By the end of 1996, these "outsiders" owned 52% of the cages in Cirata (see Table 4) and had acquired nearly complete control over the marketing sectors. The West Java Provincial Fisheries Agency made government regulations on the cage industry specifying that only displaced persons could get permits to use the reservoir waters for aquaculture and fisheries. These regulations were later codified into provincial laws, stipulating that only the displaced people were allowed to operate cages and that the number of cages could not exceed four cages per family. The permitting process was to be controlled by the Fisheries Department.

However, by 1994 outsiders had found that the back door route was an easy way to obtain access, and they paid off government agents, village leaders, and other local people to get permits. Outsiders undermined the ownership of the new aquatic resources with their financial abilities to employ the displaced persons as managers or laborers in the cage industry in return for shadow ownership. The aquaculture permit was in the name of a displaced person, but the owner was an absentee waterlord in the city. Consolidation of the aquaculture industry into the hands of the rich puts into question any long-term social benefits of the project (Zerner, 1992).

2. *Multidisciplinary nature of the efforts.* Although commendable, such multidisciplinary environmental efforts require more administration than traditional, disciplinary ones. Such extra administrative efforts must be funded. In this case, they were not. It was difficult to coordinate all of the professionals needed for project implementation. Many persons had difficulty seeing beyond the narrow bounds of their professional training. It was felt, however, that a developmental situation would have been even worse if the project had been led by a conventional fisheries or aquaculture research organization rather than by an ecology institution. Ecologists, in general, have a more generalist training and overall were more sensitive to interactions and interfaces.

3. *Vague nature of institutional agreements and responsibilities.* The institutional framework for project implementation between electric company, university, fisheries, and regional and village political institutions had to be created by the project, necessitating the previously mentioned larger than anticipated administrative load. In addition, each institution occasionally (and repeatedly) had its own interpretation of what the project agreement actually said. And in some cases, these separate institutions actually carried out their interpretations of the agreements without communicating with others, causing duplication and disagreements.

4. *Self-pollution.* IOE and ICLARM (1989) calculated the aquaculture carrying capacity of the two reservoirs as 16,400 cages (5,800 in Saguling and 10,600 in Cirata). Depending on the availability of adequate numbers of fingerlings, each cage could produce, conservatively, 1 to 3 tons fish/year or a final carrying capacity of 16,400 to 49,200 tons of fish per year (Costa-Pierce & Hadikusumah, 1990). IOE and ICLARM (1989) also included a dispersal of cages throughout most of the suitable sites for cages (deep, sheltered, and well-flushed bays) (see Figure 2). This areal distribution of cages did not occur. Farmers crowded into a very few select bays of the Saguling reservoir (southern Bongas region) and Cirata reservoir (Janggari region) due to better availability of the village and economic infrastructures and better access to large fish markets in Sukabumi, Bandung, and Jakarta. This crowding led to self-pollution by the cages due to waste feed and nitrogen discharges from the cages (and the wastes of an increasing number of residents on the surface of the water) (Soemarwoto et al., 1990). The result has been development of nuisance algal blooms and more frequent oxygen depletions, leading to large fish kills.

5. *Industrial pollution.* In the 1990s, Indonesia experienced high rates of industrial growth, especially in the manufacturing sector. In the Saguling-Cirata reservoir region, there has been especially rapid growth in the textile industry. Some of these textile mills discharged untreated wastes into the Saguling reservoir and were cited by residents as causing fish kills. Industrial wastes discharged to the reservoirs threaten the very basis of the entire cage aquaculture developments and are a principal concern to the public and product safety now and into the future.

The Lack of Social Sustainability: Aquaculture's Role in Equity and the Rural Poor

Aquaculture development has often promised the rural poor in developing countries increased access to rural jobs and better incomes in an environmentally sensitive, nonpolluting business. In this case study, however, even strong government laws and other regulations controlling access, the number of cages (four per family), and a permitting system reserved only for displaced persons could not stop the new aquaculture industry from being usurped and consolidated into the hands of the urban rich. In addition, planning could not stop the haphazard crowding of cages into a very few areas of the reservoirs where the wastes caused self-pollution and economic losses. Benefits of the new reservoir aquaculture enterprises in Indonesian reservoirs have accrued increasingly to those with adequate capital and power who are not displaced

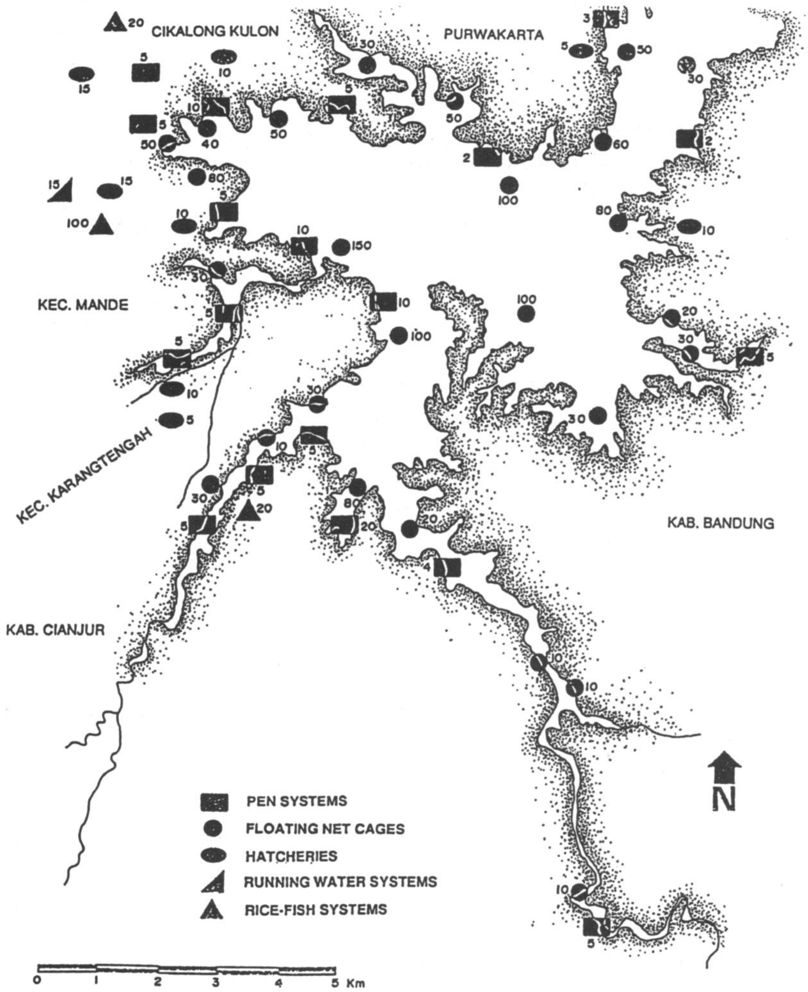

Figure 2: Aquaculture Development Plan for the Cirata Reservoir
Source: Effendi (1988).
Note: The plan portions water-based aquaculture systems (floating cages, net pens) and land-based aquaculture systems (hatcheries, rice field fish nurseries, and intensive running water systems) in and around the 6,200 ha reservoir. Effendi (1988) forecast aquaculture production from floating cages in Cirata to be 1,567 tons by 1992. Fish aquaculture production in Cirata actually grew much more rapidly; annual fish production reached 3,880 tons by 1992 (see Table 3). Administratively, the reservoir was located in two regions (Bandung and Cianjur; kabupaten = kab.) and four districts (kecamatan = kec.) of kabupaten Cianjur.

persons (see Table 4). The poorest of the displaced residents have been largely resigned to laboring in the industry rather than controlling it.

The institutional will to enforce control over access has evaporated when cage numbers exceeded the guidelines and problems appeared. Although the fisheries department is the responsible authority for the cages, the water resources directorate owns the water, and the State Electric Company owns the dam and the reservoir bottom. Yet, none of these agencies is willing to restrict new cage development or enforce its own laws (T. Walton, personal communication, 1997). In addition, there is a new problem, because in the drive for privatization, the reservoirs are now operated not by the PLN but by wholly owned subsidiary companies of the PLN.

However, there have been a number of positive, trickle-down type of benefits for the rural poor. It has been estimated that the new aquaculture industry created many new jobs in a rural area of severe underemployment (22 new types of rural jobs have been documented) (Costa-Pierce, 1997). These new jobs were higher paying (it has been estimated that cage aquaculture workers earned about Rp 56,000 per month more than rice field workers in the same area), and the new work was less rigorous than hard labor in rice paddies (Costa-Pierce, 1997). In 1992, it was estimated that 7,527 persons were employed either full- or part-time in the reservoir aquaculture industry in the two reservoirs: 1,162 directly and 6,365 indirectly (Costa-Pierce, 1997). More difficult to discern is whether the trickle-down benefits are due to these new and high-paying aquaculture jobs or are simply due to the increased economic opportunities that have been available to most of Java in the 1990s.

The Lack of Environmental Sustainability: How to Ensure Sustainability of Cage Aquaculture Production in Tropical Reservoirs

The West Java Provincial Fisheries Agency led the drafting of two 5-year plans for reservoir aquaculture development in Saguling (1985-1989) and Cirata (1988-1992) (Effendi, 1985, 1988). Plans called for a stepwise development of cage aquaculture with 3,195 tons of fish to be produced from cages in Saguling and Cirata in equal amounts by 1992 (6,390 tons total) along with development of other land and water-based aquaculture support systems (see Tables 5 and 6). Cage aquaculture developed much more rapidly and in a much more haphazard fashion. Instead of 6,390 tons by the end of 1992, fish production was estimated at 7,933 tons (see Table 3). The IOE and ICLARM (1989) reservoir fisheries and aquaculture development plan estimated a carrying capacity of 5,800 cages for Saguling and 10,600 for Cirata, or 16,400 total fish cages distributed throughout the reservoirs (see Figure 2). There were an estimated 25,558 cages in Cirata in 1996 (see Table 4), and these were crowded into very

Table 5

5-Year Step-by-Step Development Plan for the Development of Aquaculture Systems for Resettlement in the Saguling and Cirata Reservoirs

		Number per Year						Production per Year					
Activity	*Unit*	*85*	*86*	*87*	*88*	*89*	*Total*	*85*	*86*	*87*	*88*	*89*	*Total*
Floating net cages	7 × 7 × 2.5 m	75	230	340	340	355	1,340	337.5	1,035	1,530	1,530	1,597.5	6,030
Pens	1 ha	35	20	15	15	15	100	63	36	27	27	27	180
Hatcheries	1,500 m^2	52	2	2	2	2	60	24,128	928	928	928	928	27,840

Source: Effendi (1985, 1988).

Table 6

5-Year Plan for Fisheries Development in the Cirata Reservoir, West Java, Indonesia

		Number per Year						*Production per Year*					
Activity	*Unit*	*88*	*89*	*90*	*91*	*92*	*Total*	*88*	*89*	*90*	*91*	*92*	*Total*
Floating net cages	$7 \times 7 \times 2.5$ m	75	230	340	340	355	1,340	337.5	1,035	1,530	1,530	1,597.2	6,030
Pens	1 ha	27	24	15	15	15	96	156.6	139.2	87	87	87	556.8
Hatcheries	1,500 m^2	20	18	16	14	14	80	9,280	8,352	7,424	6,496	5,568	37,120
Running water	100 m^2	5	4	2	2	2	15	25	20	10	10	10	75
Rice-fish	1 ha	115	15	10	10	10	160	40.3	5.3	3.5	3.5	3.5	56.1

few areas. As a result, more frequent oxygen depletions have occurred since 1993, leading to large fish kills in Saguling (more than 500 tons in 1994-1995).

There is a significant role for an ecosystems approach to developing aquaculture by designing nonpolluting aquaculture ecosystems and closing biogeochemical nutrient cycles as an alternative approach to the "feedlot" aquaculture scenarios (Costa-Pierce, 1996; Folke & Kautsky, 1992). High-nutrient inputs enter the reservoirs from surrounding urban areas, making a high biomass of plankton available year-round. Plankton could be cropped by fish in cages in extensive or no-feed cage culture of the tilapias and Chinese carps (Costa-Pierce, 1997; Hai & Zweig, 1987). In addition, condominium cages having one insert cage suspended above another with fish that are fed and an outer cage having a crop of fish that is unfed could increase fish production from the same area of water surface, increase feed efficiency, and decrease self- and external environmental pollution (Costa-Pierce, 1997). It is recommended that an expansion of no-feed cage aquaculture systems for Chinese carps and tilapias be developed and that more emphasis on development of land-based hatcheries and rice-fish nursery systems be given. Emphasizing an ecosystems approach and developing ecosystems technologies would also better concentrate aquaculture's local economic development and multiplier effects.

Conclusion

Due to uncontrolled population growth and increased demands for water and power, there has been a boom in hydropower construction since the 1950s, especially in Asia. New methods are needed to manage reservoirs for sustainable food production and restore the livelihoods of displaced peoples. In these studies, an interdisciplinary, social-ecological approach was used to develop aquaculture as a means of local population resettlement and income restoration. Village participatory research methods were used to develop a basket of low-cost aquaculture systems and encourage development of intimate societal interactions with the new land-water aquatic ecosystems in villages most impacted from hydropower reservoirs, as opposed to moving people far away from these new environments. There are numerous situations in the developing countries of Asia where this paradigm may be of interest.

Aquaculture's role in sustainable rural development must be determined by the agenda of the intended beneficiaries. Sophisticated traditional methods of aquatic ecosystems management exist in numerous developing nations, especially in Asia. By involving the target group from the outset to develop a step-by-step technology and social adaptation program, we have evolved a set of appropriate technologies based on traditional aquaculture ecosystems in the Saguling-Cirata reservoir region that presents an exciting new model of large-scale protein food production for protein-hungry Asia. It is argued that social and environmental restoration of damaged watersheds from dam construction can only be accomplished through such active involvement of displaced people who have an investment in rehabilitation. In this case, an integrated program using the principles of farming systems research and extension methods allowed the necessary flexibility of choices to be made by the people themselves on the best component technologies they could capitalize on and manage. Reservoirs offer unique opportunities to educate people about their new environments and for formulating innovative, flexible, and evolutionary ownership patterns and agreements between electric companies, research institutions, nongovernmental organizations, and communities to meet a common set of restoration goals.

Few reported aquaculture development experiences in any country have met with such remarkable success in as short a period of time as the reservoir cage aquaculture developments in Saguling and Cirata in Indonesia. But success of the fish cage aquaculture industry can not only be measured by tons of fish. These aquaculture systems are fragile and presently are unsustainable both environmentally and socially. This study shows clearly that sustainability of aquaculture requires government support in the form of technical extension inputs, strict enforcement of its own regulations on access permits, systems numbers and pollutant discharges, and clear institutional commitments to equity. If a means could be found to ensure the more equitable distribution of long-term benefits to the target group, this notion of developing floating cage aquaculture in artificial reservoirs as a new source of aquatic protein could, in the future, represent a new, globally important food resource.

The development scenario reviewed here is characterized by rapid, dynamic, and constant change. For this reason, it is recommended that comprehensive, long-term studies of the fish cages and the people be done. These people have made a huge social leap from being principally highland rice farmers to fish farmers, transiting in a few short years from being land farmers to water farmers. They are a remarkable group of people and a unique living laboratory of new indigenous knowledge. These people could teach us a great deal about the global and localized factors contributing to success and provide more accurate forecasts for scientists and policy makers to better judge the applicability of the aquaculture resettlement option to other developing countries.

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References

Alam, M., Mirza, M., & Maughan, O. (1995). Constraints and opportunities in planning for the use of natural resources in developing countries: Example of a hydropower project. *Environmental Conservation, 22*, 352-358.

Brown, L. (1997). Facing the prospect of food scarcity. In L. Brown (Ed.), *State of the world* (pp. 23-41). Washington, DC: Worldwatch.

Cernea, M. (1988). *Involuntary resettlement in development projects*. Washington, DC: World Bank.

Cernea, M. (1997). The risks and reconstruction model for resettling displaced populations. *World Development, 25*, 1569-158.

Chambers, R., Pacey, A., & Thrupp, L. (Eds.). (1989). *Farmers first: farmer innovation and agricultural research*. London: Intermediate Technology.

Chookajorn, T. (1982). Cage fish culture in reservoirs in Singapore. *Thai Fisheries Gazette, 35*, 661-665.

Collier, W. L., Hadikoesworo, H., & Saropie, S. (1977). *Income, employment, and food systems in Javanese coastal villages*. Athens: Ohio University, Center for International Studies.

Costa-Pierce, B. A. (1992). Rice-fish systems as intensive nurseries. In C. De la Cruz, C. Lightfoot, B. Costa-Pierce, V. Carangal, & M. Bimbao (Eds.), *Rice-fish research and development in Asia* (pp. 117-130). Manila, Philippines: International Center for Living Aquatic Resources Management.

Costa-Pierce, B. A. (1996). Environmental impacts of nutrients discharged from aquaculture: Towards the evolution of sustainable, ecological aquaculture systems. In D. J. Baird, M.C.M. Beveridge, L. A. Kelly, & J. F. Muir (Eds.), *Aquaculture and water resource management* (pp. 81-113). Oxford, UK: Blackwell Science.

Costa-Pierce, B. A. (1997). From farmers to fishes: Developing reservoir aquaculture for people displaced by dams (Tech. Paper No. 369). Washington, DC: World Bank.

Costa-Pierce, B. A. (in press). *Ecological aquaculture. The evolution of the blue revolution*. Oxford, UK: Blackwell Science.

Costa-Pierce, B. A., Bimbao, M. A., Zainal, S., & Effendi, P. (1989). ICLARM and south-south technology transfer: Philippine aquaculture technology and Indonesia: Part 2. *Naga, The ICLARM Quarterly, 12*, 14-16.

Costa-Pierce, B. A., & Effendi, P. (1988). Sewage fish cages of Kota Cianjur. *Naga, The ICLARM Quarterly, 11*, 7-9.

Costa-Pierce, B. A., & Hadikusumah, H. (1990). Research on cage aquaculture systems in the Saguling Reservoir, West Java, Indonesia. In B. A. Costa-Pierce & O. Soemarwoto

(Eds.), *Reservoir fisheries and aquaculture development for resettlement in Indonesia* (pp. 112-217). Manila, Philippines: ICLARM.

Costa-Pierce, B. A., & Hadikusumah, H. (1995). Production management of double-net tilapia Oreochromis spp. hatcheries in a eutrophic tropical reservoir. *Journal of the World Aquaculture Society, 26*, 453-459.

Costa-Pierce, B. A., Rusydi, K., Safari, A., & Wira Atmadja, G. (1989a). *Small scale hatchery for common carp*. Manila, Philippines: International Center for Living Aquatic Resources Management.

Costa-Pierce, B. A., Rusydi, K., Safari, A., & Wira Atmadja, G. (1989b). *Culture of common carp in floating cages*. Manila, Philippines: International Center for Living Aquatic Resources Management.

Costa-Pierce, B. A., Rusydi, K., Safari, A., & Wira Atmadja, G. (1989c). *Growing fish in pen systems*. Manila, Philippines: International Center for Living Aquatic Resources Management.

Costa-Pierce, B. A., & Soemarwoto, O. (1987). Proliferation of Asian reservoirs: The need for integrated management. *Naga, The ICLARM Quarterly, 10*, 9-10.

Costa-Pierce, B. A., & Soemarwoto, O. (Eds.). (1990). *Reservoir fisheries and aquaculture development for resettlement in Indonęsia*. Manila, Philippines: ICLARM.

Costa-Pierce, B. A., Wira Atmadja, G., Rusydi, K., & Safari, A. (1989). *Growing fish in cages*. Manila, Philippines: International Center for Living Aquatic Resources Management.

Costa-Pierce, B. A., Zainal, S., & Effendi, P. (1988). ICLARM and south-south technology transfer: Philippine aquaculture technology and Indonesia: Part 1. *Naga, The ICLARM Quarterly, 11*, 10-11.

Dahlman, C. J., & Westphal, L. E. (1981). The meaning of technological mastery in relation to the transfer of technology. *Annals of the American Academy of Political Science, 458*, 12-25.

De la Cruz, C., Lightfoot, C., Costa-Pierce, B. A., Carangal, V., & Bimbao, M. (Eds.). (1992). *Rice-fish research and development in Asia*. Manila, Philippines: International Center for Living Aquatic Resources Management.

De Silva, S. S. (1988). The reservoir fishery of Asia. In S. S De Silva (Ed.), *Reservoir fishery management and development in Asia* (pp. 19-28). Ottawa, Canada: International Development Research Centre.

De Silva, S. S. (1992). *Reservoir fisheries of Asia*. Ottawa, Canada: International Development Research Centre.

Djajadiredja, R., Jangkaru, Z., & Junus, M. (1980). Freshwater aquaculture in Indonesia, with special reference to small scale agriculture-aquaculture farming systems in West Java. In R. Pullin & Z. Shehadeh (Eds.), *Integrated agriculture-aquaculture farming systems* (pp. 143-166). Manila, Philippines: International Center for Living Aquatic Resources Management.

Effendi, P. (1985). *Fisheries development program in Saguling during the national five year plan, 1985-89*. Bandung, Indonesia: West Java Provincial Fisheries Agency.

Effendi, P. (1988). *Fisheries development program in Cirata during the national five-year plan, 1988-92*. Bandung, Indonesia: West Java Provincial Fisheries Agency.

Engleman, R. (1995). Feeding tomorrow's people from today's land. *Environmental Conservation, 22*, 97-98.

Engleman, R., & LeRoy, P. (1995). *Conserving land: population and sustainable food security*. Washington, DC: Population Action International.

Fearnside, P. (1997). Transmigration in Indonesia: Lessons from its environmental and social impacts. *Environmental Management, 21*, 553-570.

Firman, T., & Dharmapatni, I.A.I. (1995). The challenges to sustainable development in the Jakarta metropolitan region. *Habitat International, 18*, 3-15.

Fliegel, F. C. (1984). Extension communication and adoption process. In B. E. Swanson (Ed.), *Agricultural extension: A reference manual* (pp. 77-88). Rome: Food and Agriculture Organization.

Folke, C., & Kautsky, N. (1992). Aquaculture with its environment: prospects for sustainability. *Ocean and Coastal Management, 52,* 457-472.

Folke, C., Kautsky, N., & Troell, M. (1994). The costs of eutrophication from salmon farming: Implications for policy. *Journal of Environmental Management, 40,* 173-182.

Gardner, G., & Perry, J. (1995). Big-dam construction is on the rise. *Worldwatch, 8,* 36-37.

Gonzales, E. R. (1984). Small scale tilapia cage technology adopted in fishing villages in Laguna Lake, Philippines. *Aquaculture, 41,* 161-169.

Guerrero, R. D. III. (1982). Development, prospects and problems of the tilapia cage culture industry in the Philippines. *Aquaculture, 27,* 313-315.

Hai, L. Y., & Zweig, R. D. (1987). Cage culture in Kunming: An effective means of resource recovery. *Aquaculture Magazine, 13,* 28-31.

Hunter, J. M., Rey, L., & Scott, D. (1983). Man-made lakes—man-made diseases. *World Health Forum, 4,* 177-182.

Institute of Ecology (IOE), & International Center for Living Aquatic Resources Management (ICLARM). (1989). *Final report. Development of aquaculture and fisheries activities for resettlement of families from the Saguling and Cirata reservoirs: Volume 1. Executive summary and management plan.* Bandung, Indonesia: Institute of Ecology, Padjadaran University; Manila, Philippines: International Center for Living Aquatic Resources Management.

Kang, J. T., & Song, H. K. (1984). Individual and group extension teaching methods. In B. E. Swanson (Ed.), *Agricultural extension: a reference manual* (pp. 130-143). Rome: Food and Agriculture Organization.

Kautsky, N., Berg, H., Folke, C., Larsson, J., & Troell, M. (1997). Ecological footprint for assessment of resource use and development limitations in shrimp and tilapia aquaculture. *Aquaculture Research, 28,* 753-766.

Koesoemadinata, S., & Costa-Pierce, B. A. (1992). Status of rice-fish culture in Indonesia, In C. R. De la Cruz, C. Lightfoot, B. A. Costa-Pierce, V. R. Carangall, & M. P. Bimbao (Eds.), *Rice-fish research and development in Asia* (pp. 45-62). Manila, Philippines: International Center for Living Aquatic Resources Management.

Kusnadi, E. W., & Lampe, H. (1990). Marketing of common carp from the Saguling reservoir. In B. A. Costa-Pierce & O. Soemarwoto (Eds.), *Reservoir fisheries and aquaculture development for resettlement in Indonesia* (pp. 240-256). Manila, Philippines: International Center for Living Aquatic Resources Management.

Lelek, A. (1984). Ecological aspects of the damming of a river in Borneo. *Applied Geography and Development, 24,* 59-73.

Lightfoot, C. (1987). Indigenous research and on-farm trials. *Agricultural Administration and Extension, 24,* 79-89.

Little, D., & Muir, J. (1987). *A guide to integrated warmwater aquaculture.* Stirling, Scotland: Institute of Aquaculture.

Maskana, S., Astuti, S., Sudiarto, B., & Soemarwoto, O. (1990). Integrated system for environmental management in the Saguling-Cirata reservoir region. In B. A. Costa-Pierce & O. Soemarwoto (Eds.), *Reservoir fisheries and aquaculture development for resettlement in Indonesia* (pp. 370-378). Manila, Philippines: International Center for Living Aquatic Resources Management.

McCully, P. (1996). *Silenced rivers. The ecology and politics of large dams.* London: Zed Books.

Munro, J., Iskandar, & Costa-Pierce, B. (1990). Fisheries of the Saguling reservoir and a preliminary appraisal of management options. In B. A. Costa-Pierce & O. Soemarwoto (Eds.), *Reservoir fisheries and aquaculture development for resettlement in Indonesia* (pp. 285-328). Manila, Philippines: International Center for Living Aquatic Resources Management.

Petr, T. (1978). Tropical man-made lakes—Their ecological impact. *Archives fur Hydrobiologie, 81,* 368-385.

Pimental, D., Houser, J., Preiss, E., White, O., Fang, H., Mesnick, L., Barsky, T., Tariche, S., Schreck, J., & Alpert, S. (1997). Water resources: Agriculture, the environment, and society. *BioScience, 47,* 97-106.

Pollnac, R. B. (1982). Sociocultural aspects of implementing aquaculture systems in marine fishing communities. In L. J. Smith & S. Peterson (Eds.), *Aquaculture development in less developed countries* (pp. 31-52). Boulder, CO: Westview.

Pollnac, R., & Sihombig, S. (1996). Cages, controversies and conflict: Carp culture in Lake Toba, Indonesia. In C. Bailey, S. Jentoft, & P. Sinclair (Eds.), *Aquaculture development. Social dimensions of an emerging industry*. Boulder, CO: Westview.

Postel, S., Daily, G., & Ehrlich, P. (1996). Human appropriation of renewable fresh water. *Science, 271*, 785-788.

Pullin, R.S.V. (1986). Aquaculture development in Nepal—Pointers for success. *Naga, The ICLARM Quarterly, 9*, 9-10.

Rifai, S. (1985). *Experimental project in floating net cages in the Saguling Reservoir*. Bandung, Indonesia: Padjadjaran University.

Ruddle, K., & Zhong, G. (1988). *Integrated agriculture-aquaculture in South China*. Oxford, UK: Oxford University Press.

Rusydi, K., & Lampe, H. (1990). Economics of floating net cage common carp culture in the Saguling Reservoir, West Java, Indonesia. In B. A. Costa-Pierce & O. Soemarwoto (Eds.), *Reservoir fisheries and aquaculture development for resettlement in Indonesia* (pp. 218-239). Manila, Philippines: ICLARM.

Soemarwoto, O., Roem, C., Herawti, T., & Costa-Pierce, B. A. (1990). Water quality suitability of the Saguling and Cirata reservoirs for floating net cage aquaculture. In B. Costa-Pierce & O. Soemarwoto (Eds.), *Reservoir fisheries and aquaculture development for resettlement in Indonesia* (pp. 18-111). Manila, Philippines: ICLARM.

Sutandar, Z., Costa-Pierce, B. A., Iskandar, A., Rusydi, K., & Hadikusumah, H. (1990). The aquaculture resettlement option in the Saguling reservoir, Indonesia: Its contribution to an environmentally-oriented hydropower project. In R. Hirano & I. Hanyu (Eds.), *The second Asian fisheries forum* (pp. 253-258). Manila, Philippines: The Asian Fisheries Society.

Suwartapradja, O. S., & Achmad, H. (1990). Population density and general socioeconomic conditions around the Saguling and Cirata reservoirs. In B. Costa-Pierce & O. Soemarwoto (Eds.), *Reservoir fisheries and aquaculture development for resettlement in Indonesia* (pp. 7-17). Manila, Philippines: ICLARM.

Thompson, S. (1995). *The evolving grain markets in Southeast Asia. In USDA, Foreign Agriculture Service, Grain: World markets and trade*. Washington, DC: United States Department of Agriculture.

Thornburn, C. (1982). *Teknologi kampungan: A collection of indigenous Indonesian technologies*. Stanford, CT: Volunteers in Asia.

West Java Provincial Fisheries Service. (1996). *Internal report on Saguling and Cirata Fishcages*. Bandung, Indonesia: Author.

World Bank. (1982). *Fishery sector policy paper*. Washington, DC: Author.

Zerner, C. (1992). Development of small-scale freshwater cage culture fishery in reservoirs in Java: Legal, environmental, and socioeconomic issues. In R. B. Polnac, C. Bailey, & A. Poernomo (Eds.), *Contributions to fishery development policy in Indonesia*. Jakarta, Indonesia: Central Research Institute for Fisheries.

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