Ecological Aquaculture: The Evolution of the Blue Revolution
Edited by Barry A. Costa-Pierce

Part 3

The Context of Ecological Aquaculture

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Chapter 7

Village-based Aquaculture Ecosystems as a Model for Sustainable Aquaculture Development in Sub-Saharan Africa

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Introduction

Aquaculture in Southern Africa is growing in part due to new approaches to project design and implementation begun in the late 1980s by:

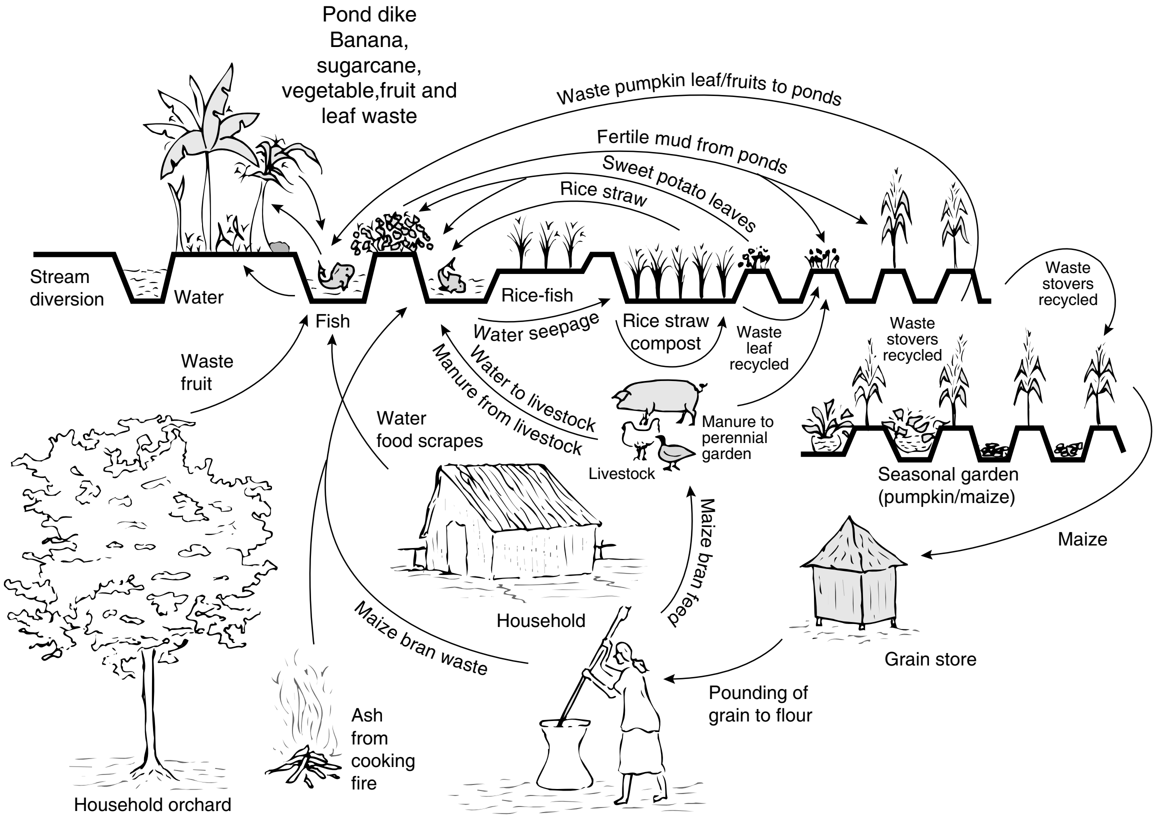
- the Food and Agriculture Organization of the United Nations (FAO) project 'Aquaculture for Local Communities Management', funded by Sweden and Belgium;
- the German Agency for Technical Cooperation project 'Malawi–German Fisheries and Aquaculture Development'; and
- ICLARM's 'Research for the Development of Tropical Aquaculture' in Malawi, and 'Research for the Future Development of Aquaculture' in Ghana.

These projects generally followed FAO guidelines described in the Thematic Evaluation of Aquaculture (FAO/NORAD/UNDP, 1987) to develop technologies, to increase awareness, and to reorient extension approaches to make them more participatory. We report here on progress in the development of a village-based approach to integrated aquaculture ecosystems with a fishpond as the focal point for recycling of by-products generated by other farm enterprises. This approach is a potentially important new advance in evolving sustainable aquaculture systems appropriate to the social, environmental and economic situations in rural Africa (Box 7.1).

Village aquaculture ecosystems (VAEs) have been shown to improve productivity (Smalling *et al*., 1996), increase sustainability (Lightfoot *et al*., 1993), decrease waste, and even rehabilitate degraded rural landscapes (Pullin & Prein, 1995). If applied over larger areas, VAEs have the potential to reduce rural poverty and food insecurity by offering realistic opportunities for diversification and enhanced efficiency to African farmers whose land holdings are shrinking (Dalsgaard *et al*., 1995; Hoque, 1995; Alarcón & Carls, 1996; Harris, 1996; Smalling *et al*., 1996).

Box 7.1 Integrated resource management

Since 1985, ICLARM, with financial support from Germany, Denmark and the US, has conducted research into the development of integrated aquaculture techniques for use by African smallholding farmers. In collaboration with researchers, farmers develop maps (such as that shown below) of their farming systems. From this, farmers get new ideas about integrated resource management and often see their farms holistically for the first time. Through on-farm and on-station experiments, researchers, quantify the various resources flows (indicated by arrows) on the map to gain socio-economic and ecological insights into integrated African farming systems.



The potential impacts of VAEs on African food security are enormous. Small farms account for the vast majority (97% in 1989) of aquaculture production in Sub-Saharan Africa (King, 1993). According to an FAO study,

> 'There are some 9.2 million km^2, equivalent to 31% of the African surface, containing area apt for warm water fish farming at a subsistence level. Of the 48 countries, 40 possess at least some land apt for this use.'
>
> (Kapetsky, 1994)

Farm trials in Malawi have shown that fish yields on VAEs range from 1000 to 3000 kg/ha/year (Costa-Pierce *et al.*, 1991; Chikafumbwa *et al.*, 1993; Brummett & Noble, 1995a, b). If this production can be replicated on only 1% of the suitable land, 9.2–27.6 million mt of fish per year might be produced. This is between two and six times the catch from Africa's capture fisheries (FAO, 1989). However, extrapolating from land that might be suitable for fish farming to potential economic and environmental impacts of integrated aquaculture on small farmers must be viewed with caution.

Despite steady growth, realizing the full potential of aquaculture on Africa's suitable lands has been elusive. Many development projects have relied on 'modules' or 'technology packages' such as duck–fish or chicken–pig–fish production units. Such technologies are developed and tested for economic efficiency on experiment stations, then promoted among extension agents for transmission to farmers. These technologies are found to be highly lucrative only if implemented in their entirety, and are often beyond the financial means of the majority of the target group. Lack of funds to implement the system leads to a situation where extension agents must travel long distances to interact with those few farmers who are capable of using the experiment station approach.

The ways in which rural farmers with small land holdings ('smallholders') make decisions about technology adoption are complex (Brummett & Haight, 1996). Likewise, there is a high degree of variability within and among smallholder farming agroecosystems (ICLARM & GTZ, 1991). To accommodate this variability, technology packages should be customized to fit individual farming situations. The Expert Consultation on Small-Scale Rural Aquaculture (Martinez-Espinoza, 1996) found that, rather than modules, new approaches to problem resolution are needed. ICLARM research in Malawi has demonstrated that VAEs might be developed in the flexible fashion required to achieve the full potential of rural fish farming in Africa.

Research to develop VAEs in Africa

Integrated farming research in Africa has evolved from simple animal or crop plus fish modules modified from Asian models, to holistic analyses of complete farming systems (ICLARM & GTZ, 1991; Noble & Costa-Pierce, 1992; Brummett, 1994). ICLARM has developed a Farmer–Scientist Research Partnership (FSRP) approach (Fig. 7.1) (Brummett & Noble, 1995a). The FSRP can be summarized as follows:

(1) Data on the farm resource base are gathered in a participatory resource mapping exercise.
(2) Weekly pond management data are used to set up parallel experimental controls and treatments at the research station and on-farm in order to provide baseline data for both farmers and researchers.
(3) Potential new technology is developed in trials conducted on the experiment station using the actual farm resource base and management as experimental controls.
(4) Results on-farm and on-station are compared in an interactive session with farmers at the end of the production cycle.
(5) Farmers compare results from (2) and (3) above to plan the next round of experimentation.

The FSRP approach to technology development involves farmers throughout and uses actual farm conditions and constraints to design new technology; consequently,

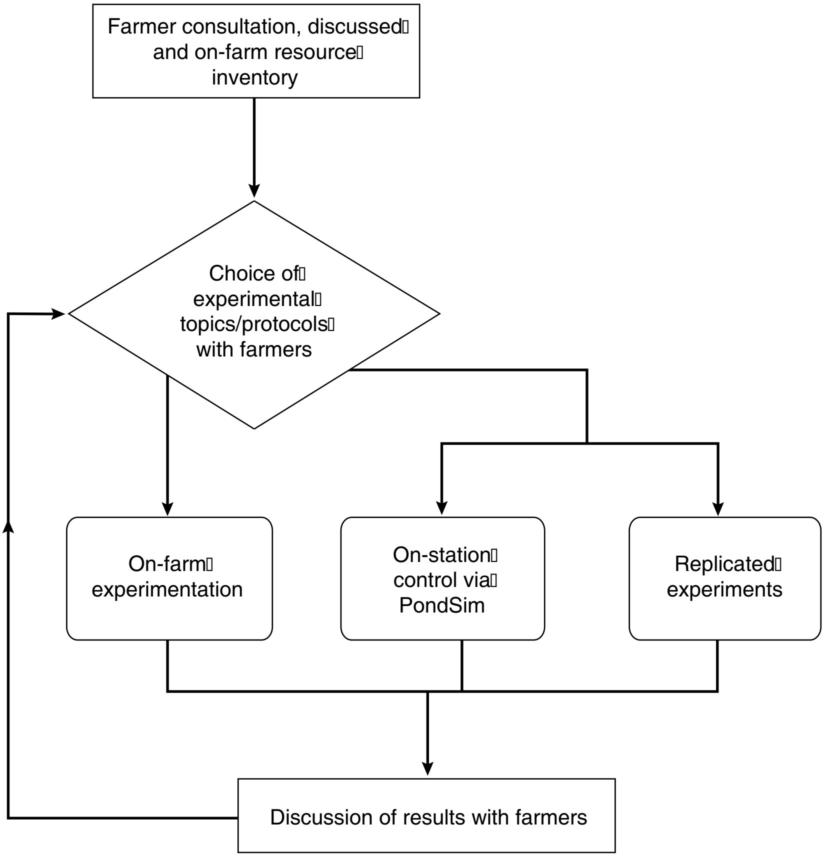


Fig. 7.1 ICLARM's Farmer–Scientist Research Partnership (FSRP) approach to the development of integrated aquaculture–agriculture (IAA) technology. PondSim is a spreadsheet package designed by ICLARM to calculate dry matter, organic matter, nitrogen and phosphorus equivalents of pond inputs used by farmers as a means of controlling on-farm conditions during experiment station trials.

it is able to obviate the necessity of *ex post facto* adaptation of research-station results to farm conditions. FSRP also establishes the necessary information base on the farming ecosystem and feedback loops for farmers and researchers to trust each other and work together effectively on problems identified collectively (Box 7.1).

Impacts on farm productivity

In Malawi, average fish productivity in the VAEs is 1350 kg/ha/year in rain-fed areas and 1650 kg/ha/year in spring-fed areas (Brummett & Noble, 1995a). These are compared to an average of about 900 kg/ha/year for the 48 most productive, non-integrated fish farms in Southern Malawi (Scholz & Chimatiro, 1996). Differences stem from the range of available pond inputs, and the location of ponds relative to other farm enterprises in the household.

On integrated farms, ponds are generally located in vegetable gardens, or vegetable gardens develop around the fish pond to take advantage of emergency irrigation water, and wastes from the garden are used to feed fish (Noble & Chimatiro, 1991; Chimatiro & Costa-Pierce, 1996). Typically, on-farm wastes amount to some 3700 kg of dry matter per year and the material is generated in close proximity to the pond, minimizing the work involved in transportation. To properly feed the typical farm pond, a farmer needs about 522 kg of dry matter (Brummett, 1998).

Non-integrated farms, on the other hand, are using maize bran exclusively, as recommended by extension, as the ‘best’ fish food (Kadongola, 1990). Maize bran production averages around 192 kg of dry matter, only 37% of the amount needed to feed a fishpond properly (Noble, 1996). In addition, on a typical Malawi farm, maize bran is produced in the house, often far from the pond, and is also a dry season ‘emergency food’ for humans (Mills, 1991). In contrast, vegetable garden wastes are typically just burned if they are not used in a pond.

Integrated fishponds have the potential to profoundly affect the economic and ecological sustainability of small farms. All of the farms involved in research were affected by drought from 1991 to 1995. Yet in all cases, even though maize crops failed and farmers suffered economic losses, integrated pond–vegetable systems kept operating through the drought. Retaining water on the land, ponds enabled farms to sustain their food production and balance their losses on seasonal croplands. For example, in the 1993/94 drought season, when only 60% of normal rain fell, the average net cash income to a study group of rain-fed integrated farms was 18% higher than the non-integrated farms; and this occurred in an area with some of Malawi’s severest poverty (Brummett & Chikafumbwa, 1995).

Technology adoption and transmission

Virtually all of the ICLARM cooperating farmers who have access to permanent water supplies continue to grow fish and improve their production (Fig. 7.2). Among

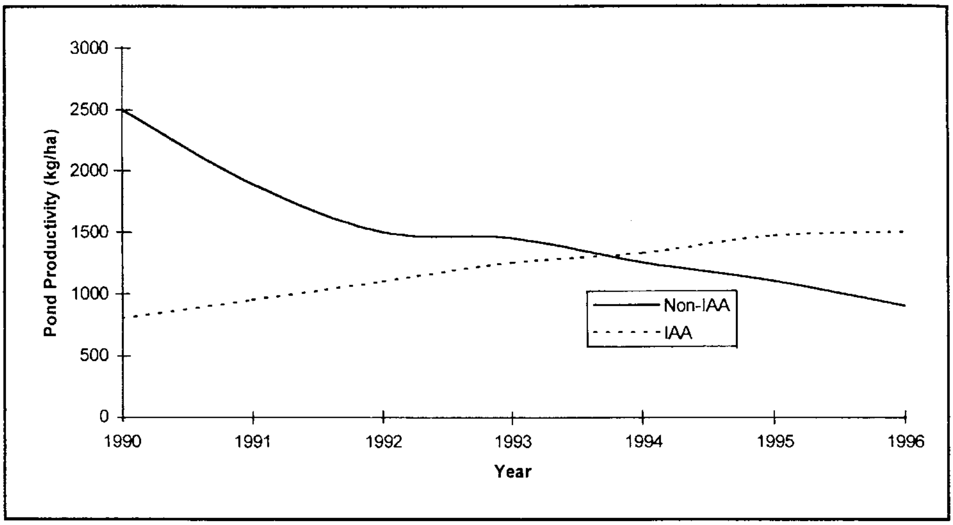


Fig. 7.2 Pond productivity over time in integrated vs non-integrated fishponds in Southern Malawi. The production target of 2500 kg/ha was arrived at by extrapolation of Malawi's national fish production need to the land area available for aquaculture. The technology promoted was too complex for most farmers to fully understand and/or adopt, resulting in declining production as extension support waned. IAA entry-level technology is much simpler and less productive initially, but evolves on-farm as farmers who understand the technology are able to more efficiently manipulate it to suit their individual situation (Brummett & Williams, 2000).

those farmers with only rain-fed fish ponds, 36% dropped out for one reason or another. Forty per cent of those dropping out did so because of family deaths or illness rather than for any agricultural reason. Those remaining have increased their average pond size from 64 to 88 m^2 and new gardens are being planted around the ponds (Brummett & Chikafumbwa, 1995).

Of the Malawian farmers who have been exposed to VAE technology through various participatory mechanisms, 86% have adopted at least one of the demonstrated technologies, 76% adopted at least two, and 24% adopted four (Noble & Rashidi, 1990). Interestingly, in follow-up interviews it was discovered that the adopters did not simply copy what they had seen, but rather took the basic ideas and modified them to suit their individual circumstances and farming systems (Brummett & Noble, 1995b).

Once in the rural community, VAE technologies spread and evolved without further extension support. A survey found that, within six months of an open day held at the experiment station in May 1990, 46% of adopters in the target area had learned about integrated aquaculture from other farmers. A third of these farmers had adopted two or more technologies from their neighbors. By the end of 1992, almost 80% of the farmers practicing integrated rice–fish farming in Zomba District had never witnessed first hand an extension demonstration (Chikafumbwa, 1994). In Zomba East, where ICLARM worked with 34 farmers from 1991 to 1995 (ICLARM & GTZ, 1991), there are now 225 practicing fish farmers (Scholz *et al.*, 1997).

Ecological footprints

Berg *et al.* (1996) reviewed the environmental sustainability of various types of aquaculture development by comparing VAEs with pellet-fed cages situated in Lake Kariba, Zimbabwe, based on the concept of ecological footprints (Table 7.1). They estimated the ecosystem support area (or ecological footprint) required for the production of feed and oxygen and for waste nutrient assimilation to support a 1 m^2 cage producing 380 g of tilapia/day. Based on the assumption that the fish meal needed would be produced locally from *kapenta* (*Limnothrissa miodon*; a pelagic clupeoid), production of 1 kg of caged tilapia would require 4.3 kg of *kapenta* and 0.9 kg of grain. The fish meal alone required to produce 2000 mt of tilapia in cages would thus appropriate an area almost 21 000 times the area of the cages themselves. Producing 2000 mt of fish in cages would require over 8000 mt of *kapenta*, corresponding to 40% of the total annual catch in Lake Kariba and a net loss in available fish protein for the human population.

Table 7.1 Ecological efficiency of two aquaculture systems (modified from Berg *et al.*, 1996)

To support a 1 m^2 tilapia cage in Lake Kariba requires:

21 000 m^2 of water area to grow fishmeal
420 m^2 of crop land to grow grains
160 m^2 of phytoplankton to produce oxygen
115 m^2 of benthic community to assimilate waste phosphorus

21 700 m^2 'ecological footprint' (6 g fish per m^2 of footprint)

To support 1 m^2 of waste-fed integrated fish pond requires:

0.9 m^2 of additional benthic community to assimilate phosphorus
0.9 m^2 of phytoplankton to produce oxygen

1.8 m^2 'ecological footprint' (264 g fish per m^2 of footprint)

Although relatively minor compared with the area needed for food production, the support area for oxygen production and nutrient assimilation was also significant. The surface area of primary production required to produce the oxygen consumed directly by fish in the cages and by the organic waste produced at the farm (fish feces and feed fragments) was 160 times larger than the area of the cages. Assimilation of nutrients released to the environment as a result of feeding and metabolism of the fish required an area 115 times larger than the area of the cages.

In contrast, the ecological footprint of VAEs is minuscule. Feed inputs to ponds are based entirely on wastes from agriculture. The relatively low fish production per unit of area in the ponds means the ecological footprint needed for oxygen production and nutrient assimilation can be sustained within the pond system itself. Hence, a minimum of external (e.g. off-farm) life or feed supports are needed to farm tilapia in integrated village ponds.

This comparative analysis shows that there is a severe risk that cage aquaculture would be a substitute and not a complement to the existing fishery in Lake Kariba. On the other hand, as long as on-farm waste products are the only feeds, the VAEs would complement not deplete the *kapenta* fishery.

Environment, economics and food security

The advantages of VAEs are clear if one only considers longer-term environmental impacts and overall efficiencies of resource use. However, short-term economics for cages often favor the more intensive system, at least on paper. This is because economies of scale for feed processing, storage and marketing favor the more vertically integrated producer. On the other hand, in rural Africa problems such as irregular supply of inputs and spares, unreliable power and unpredictable production and marketing conditions can hit the larger-scale producer proportionally harder than the smaller scale one.

The Lake Kariba case study illustrates the food security limitations of aquaculture when it is conceived primarily as a commercial fish production exercise based only on cash-flow models. In the case of the proposed cages, commercial fish farming, although profitable for the investors, would result in a net loss of fish protein available for human consumption.

To exacerbate this problem, many commercial aquaculture enterprises in the tropics tend to export their produce to earn the higher profits possible in richer American, European or Japanese markets (Fitzsimmons & Posadas, 1997). All of the larger-scale commercial investments in Southern African aquaculture of which the authors are currently aware, including projects in the Republic of South Africa, Namibia, Tanzania, Swaziland and Zimbabwe, are export-oriented. Most are focusing on high-value species such as shrimp and oysters or on species for which there is little or no local market (e.g. the red swamp crayfish, *Procambarus clarki*).

While providing important investment opportunities, these food production enterprises do not address Africa's quality and quantity food security problems. When locally available materials are used in the manufacture of fish foods, export-oriented commercial aquaculture directly transfers food from poor countries to richer ones. In the best case (i.e. where taxes on exports are used efficiently by government to purchase larger quantities of cheaper food more affordable to poor consumers) lower quality food is being substituted for high quality food.

Integrated smallholding-based systems, in contrast, produce direct opportunities for households to address their own food insecurity. Smallholdings sell only a portion of their harvest for cash, keeping a substantial part for household consumption (Brummett & Chikafumbwa, 1995). That portion which is sold is normally transferred to fellow smallholders in the immediate vicinity who also face problems with food quantity and quality (Brummett, 2000). Increases in overall farm productivity associated with the integration of aquaculture can result in large gains in household food production and income generation (Ruddle, 1996).

The VAE is clearly the most environmentally friendly, ecologically efficient, and socially appropriate aquaculture approach for most of rural Africa. If the ecological footprints for the two systems are inverted, one finds that the cages produce 6 g of fish per m^2 of footprint compared with 264 g for the VAE. In addition, having a larger number of widely scattered small producers ensures that microeconomic benefits will accrue to the community directly and will be more equitably distributed. Producing fish in small ponds in small communities also obviates many of the marketing problems that more centralized producers face. It also lowers the overall risk. However, one important question remains: Can small scale producers grow enough fish to make a real difference in living standards?

Economically, VAE farms produce almost six times the cash generated by the typical Malawian smallholder (Scholz & Chimatiro, 1996). The integrated pond–vegetable garden is the economic engine on these farms, generating almost three times the annual net income from the staple maize crop and the homestead combined. The vegetable–fish component contributes, on average, 72% of annual cash income (Brummett & Noble, 1995b). On a per area basis, the vegetable garden/pond resource system generates about $14.00 per 100 m^2 of land per year compared with $1.00–$2.00 for the maize crop and homestead respectively.

Realizing the potential

At the national policy level, resource utilization for aquaculture development impacting the good of the larger human population must come ahead of providing investment advice to individual entrepreneurs interested in intensive aquaculture development (Costa-Pierce & Pullin, 1992). To maximize the positive impact of resource use at the national level, we should compare not only the short-term economics of the two systems, but also how their implementation would effect distribution of wealth, sustainable use of resources and food security (ICLARM & GTZ, 1991).

The amount of time and energy involved in ICLARM research efforts has been large relative to the small numbers of farmers involved. Duplicating such efforts on a large enough scale to have widespread regional impact would probably not be cost-effective and would therefore be institutionally unsustainable (van der Mheen, 1996). However, from the experience gained over the course of these various projects, ICLARM has extracted what we feel are the key components of a new approach to the evolution of sustainable aquaculture development in rural Africa:

- ‘Bottom-up’ development planning: knowing the socio-economic, gender, and cultural context of farming households and the national policies that affect them first, *before* any interventions (ICLARM & GTZ, 1991).
- Information transfer: simple messages for farmers generated by research in dynamic consultation with extension.
- Sustained adoption: full participation of farmers in the research and development process.
- Ecological evolvability: incorporating and utilizing an ecosystems vision of the farm.

- Economic evolvability: incremental, evolutionary increases in cash productivity to overcome recurrent cash-flow constraints.

Each of these components has a technical and social dimension. The technical dimension involves determinates of how productive a new technology is likely to be under a given set of agroecological circumstances. The social dimension involves research–extension–farmer communication and decision-making leading to sustained adoption and transformation to sustainable farming ecosystems.

Information transfer and sustained adoption

ICLARM's experience in Malawi is that complex technology packages that hope to address all aspects of integrated fish production are not effective in transferring information to farmers. There are two reasons for this (Brummett & Haight, 1996):

(1) Extension agents are seldom sufficiently proficient in the technologies themselves to clearly communicate them to farmers.
(2) Farmers who are generally illiterate and operating at the subsistence level are more interested in risk management than economic analyses concerning single components of their multi-dimensional and highly variable farming ecosystems.

To overcome these problems, it is necessary to distill from farm characterizations and an in-depth understanding of aquaculture technologies a few simple techniques that are low risk in terms of capital requirement and the degree of modification to existing farming practices, but which can significantly address the perceived needs of the farming community. For example, rather than advocating the construction of a 'proper' fish pond which drains, ICLARM has successfully advocated the construction of small holes dug into existing boggy spots in farmers' fields. Such a pond is simple to construct, is easily filled by rain- and groundwater, and only costs the loss of production of some of the maize crop which was already producing poorly because of waterlogging; likewise, with harvesting technology (hook and line), production system (partial harvesting of intermediate-sized fish to maximize biomass), and pond feeding strategy (focus on fertilization value of weeds and recyclable by-products).

It is not economically or institutionally practical for a team of researchers to be the main mechanism of outreach to farmers. Unfortunately, many extension services are poorly trained and supported and hence not fully capable of choosing and then explaining to farmers the best technology for a particular situation. This problem was discussed in depth at a recent FAO Technical Consultation (van der Mheen, 1996) and several suggestions for their alleviation were put forward:

- Research should provide a 'promotion facility' which interacts with extension to analyze information coming from the field, and 'experiment stations' to find good matches between needs (both felt and unfelt) and possible solutions.

- To reach large numbers of farmers, a simplified technology should be translated into an extension message which extension and farmers can easily understand.
- Extension materials should be generated by researchers and directed at farmers rather than extension agents.
- Based on their field experience, extension agents should provide at least initial critical review of the relevance of technologies proposed by scientists.

Problems in the farmer–extension–research continuum have plagued development efforts for many years. The act of working together to identify problems and design solutions and extension messages is a better way for research and extension to overcome long-standing differences for the benefit of agricultural productivity and rural economic growth.

If implemented, these arrangements would, in effect, dissolve the separate identities of the extension and research services (Brummett & Haight, 1996). In so doing, it would bring research and extension together with a single purpose: to improve the management of smallholdings through the introduction of VAEs wherever feasible. Integration of extension and research functions will require a higher level of farmer input to the research program, as well as a higher level of technical flexibility in the extension services.

Researchers working in collaboration with farmers and extension agents should increase their sensitivity to the real problems faced in the field. Having extension agents working at the experiment station on research projects should facilitate an improvement in their practical skills and comprehension of the principles of aquaculture. The farmer should be the largest beneficiary of this collaboration by receiving higher quality information and being able to have his or her theoretical questions addressed immediately by research.

Improvements in productivity

Simple technologies may be easier to get on to the farm than complicated ones, but they also tend to be less productive. To overcome this problem, ICLARM utilizes an evolutionary approach, the FSRP, to improving overall farm productivity. Experience in Malawi has shown that working with, rather than for, farmers fosters a much more thorough understanding of technology than would be possible by even the most clearly written textbook.

For example, the extension services in Malawi have long promoted a set of technologies developed on research stations that can, if properly utilized, produce an average of 2500 kg/ha of fish. These technologies have suffered from being poorly adapted to local farms and misunderstood by both extension agents and farmers. The result is the reported average production by extension-assisted farmers of 900 kg/ha and the high dropout rates witnessed by many projects (Brummett & Haight, 1996).

In contrast, ICLARM's proposed technologies produced initially only about 800 kg/ha, but set out new participatory approaches wherein farmers and research personnel learned together how best to grow fish under a particular set of environmental and social circumstances. Development of new approaches facilitated the evolution of the growth of pond and farm productivity and increased the number of farmers involved. With this approach, pond productivity in Malawi has grown over time to an average of 1500 kg/ha (Fig. 7.2). In addition, the sense among farmers is that this growth and improvement are something they themselves have accomplished. Farmers have also been key informants in enhancing the increased rate of farmer-to-farmer transfer of technology.

To systematically document these evolutionary and new relationships, ICLARM has developed the Research Tool for Natural Resource Management and Evaluation (RESTORE), a participatory method for resource management, monitoring and evaluation. Based on four sustainability indicators (diversity, recycling, capacity and economic efficiency), RESTORE captures key information about how farming systems produce food and wealth within the context of their external and internal environments (Lightfoot & Pullin, 1995). Testing of the tool in Ghana, Malawi and the Philippines has shown RESTORE to be effective in helping farmers to understand potential synergisms within their complex farms (Lightfoot & Noble, 1993). To address the social dimension, the Farmer–Scientist Research Partnership (FSRP) has developed new relationships between farmers, extension agents and researchers.

Economic threshold for commercial transformation

With an average annual cash income of less than $10.00 per year, 80% of smallholder farmers in Malawi cannot be considered as part of the cash economy (World Bank, 1996). Macroeconomic policy changes will, consequently, have no effect on small farm productivity except possibly by making the land worth so much that smallholders will be forced to sell out to urban investors who can afford the capital investment required to make the land productive.

With no realistic options for employment, the displaced rural poor add to the social crisis now being witnessed in the cities of many developing countries. A change from rural poverty to urban poverty cannot be considered much of an improvement in the lives of these people. The projected additional cost of policing millions of displaced and unemployed smallholders alone ought to encourage a policy of keeping people productively engaged on the land.

Because they are based on expensive external inputs, the agricultural technologies of the green revolution and the industrial aquaculture factories of the late twentieth century have not been able to engender significant economic growth on impoverished small African farms. Nor will these technologies help in evolving a solution to sustaining thousands of rural farmers in the twenty-first century. Without massive infusions of external cash, increased economic productivity will have to be based on available resources.

Reardon & Vosti (1995) point out the importance of what they term ‘investment poverty’ in rural transformation. When cash flows into a farm household, immediate needs such as hospital or school fees receive first attention. Additional cash inflow might be used to purchase improved housing components (e.g. a plastic liner for a thatched roof) or some other coveted item such as a radio. Only after these recurrent cash demands are met will capital be freed for reinvestment in future agricultural production. Because of their critical role in improving the economic performance of the farming system on the basis of materials already available on the farm, and evolving new modes of economic and community sustainability, village aquaculture ecosystems may have a critical role to play in the transition of a farm from 'subsistence' to 'commercial'. It remains to be proven, through a widely promoted program of developing VAEs and rural self-sufficiency, that it is not too late to save hundreds of millions of Africa's rural poor from a life of urban poverty and social decay.

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