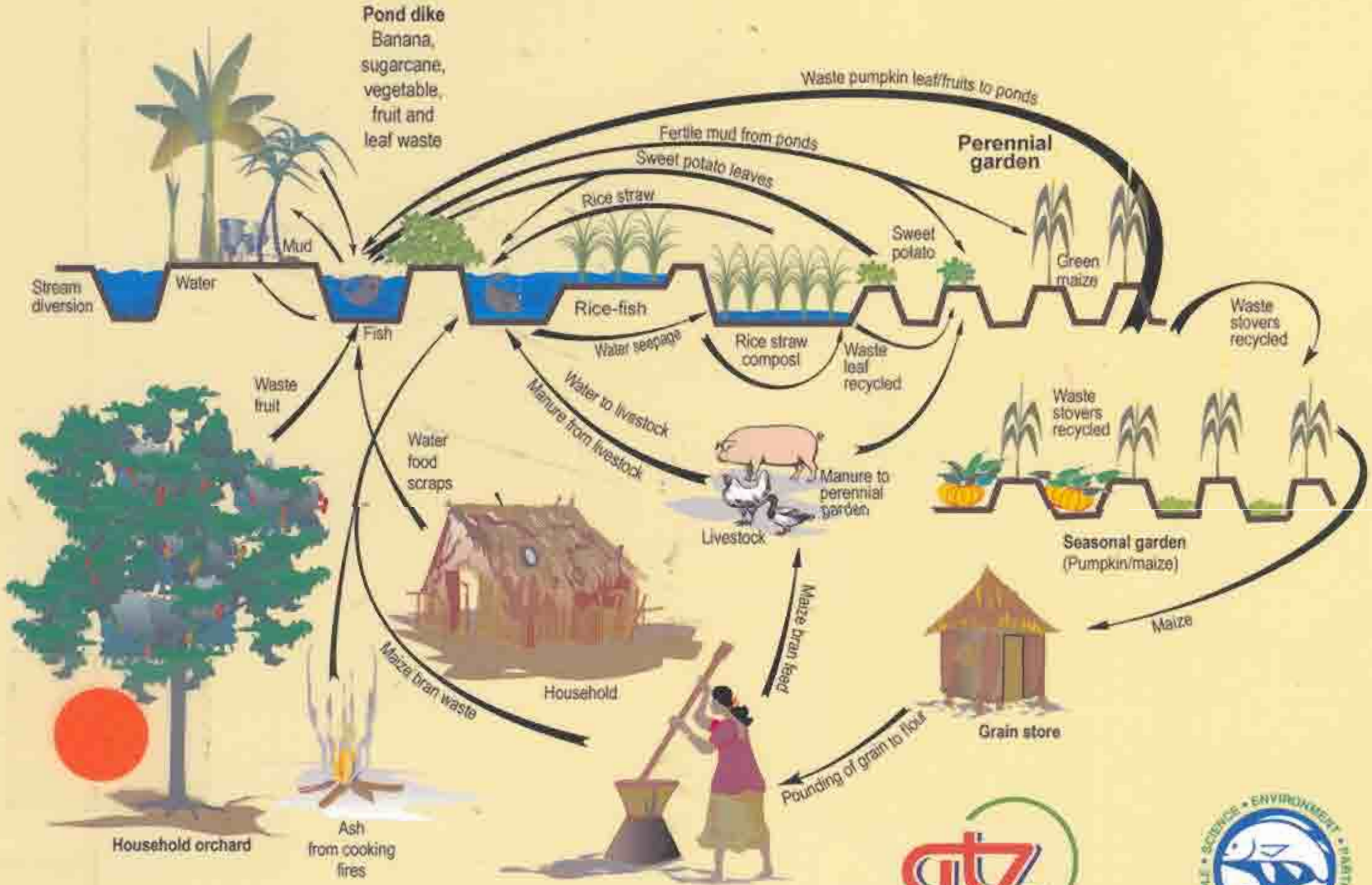
# Aquaculture for African Smallholders

**R.E. Brummett** and **R.Noble**



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R.E. Brummett
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1995

International Center for Living
Aquatic Resources Management

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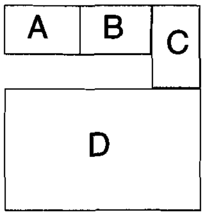
Cover: (A) Harvesting of even small rainfed ponds attracts considerable interest from villagers who are keen fish eaters. (B) ICLARM Research Associates, Fredson Chikafumbwa *(left)*, and Daniel Jamu (second from left) demonstrate hand-sexing of tilapia with cooperating farmers. (C) George Mwalabu, an ICLARM laboratory technician, analyzes benthos samples to better understand the food web in small Malaŵian ponds. Photos by R. E. Brummett. (D) Resource flows on smallholdings in Zomba District, Malaŵi; Original drawing by R. P. Noble; redrawn electronically by Albert Esquillon after a watercolor original by Albert Contemprate.



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# Foreword

Small-scale pond aquaculture has had many false starts in subSaharan Africa, dating from the colonial period. Many aquaculture commentators still doubt that it can ever be a viable proposition for adoption by resource-poor farmers or for supplying the fish needed by consumers in the rural areas and the rapidly expanding cities. The reasons for this pessimistic view include the lack of African experience in fish breeding and husbandry, the poor economic returns to cash and labor investments from pond construction and operation, and the poor fish yields, by comparison with Asia, from ponds that are by force of circumstances nutrient-starved. However, this view misses the important point that almost all attempts to develop small-scale pond aquaculture in subSaharan Africa have been initiated, implemented and evaluated by aquaculture experts with the primary objective to increase fish production and to create fish farmers. Such efforts have also been generally supported and administered by donors, agencies and institutions only to increase the supply of fish.

Recently, however, the idea has spread that a small pond on a mixed-enterprise, resource-poor, African smallholding can improve whole farm productivity and profitability as well as produce fish. A pond may transform the ecology, and therefore the productivity, of a farm, by enabling synergistic interactions among different farm enterprises: cereal crops, vegetables, fruit, sometimes a few livestock, and fish. Such a pond is best called a *farm* pond, not a fish pond. It produces some farmed fish, and is therefore an aquaculture operation, but the farm on which it is located is not primarily a fish farm, nor is the farmer primarily a fish farmer. Farm ponds might be one alternative to the larger-scale, intensive, specialized fish farms, but which would have large feed, energy and other resource requirements, planting "ecological footprints" far beyond their own boundaries, and being beyond the capital capacity of most farmers.

The wide adoption of small farm ponds could result in a sizable increase in farmed fish production in Africa, in addition to facilitating increases in other produce; especially vegetables, fruit and condiments from pond banks and margins and adjacent gardens, and from the pond bed itself in dry periods. These are not new concepts. They arose centuries ago in China and led to the evolution there of integrated farming systems which spread to a number of other Asian countries. There are a few examples of similar systems in other regions - for example, the Mayan *chinampa* system of water channels and raised beds for plants - but there is very little that is comparable in the history of subSaharan Africa.

In response to increasing pressures of population growth, industrialization and urbanization, there has been a predominance of sector-specific and commodity-specific research and development (e.g., agriculture, aquaculture, fisheries, forestry) in all developing regions and a push towards intensification and maximizing production, often regardless of environmental and social costs.

This has obscured the potentials of small-scale systems based on integrated resources management (IRM) especially since individual, institutional and corporate interests have been vested in separate sectors. Sectoral barriers are beginning to break down and the time is ripe for the development of new and sustainable systems, perhaps based on IRM. Farm ponds on African smallholdings are an example of this: farm ponds as biodigesters of waste, as providers of fertile soil and water, and as site improvements that permit new options for rotating, and linking enterprises for risk management. This is a more complex and knowledge-intensive approach than rice- and poultry- and pig-fish combinations. It is a renaissance of much earlier ideas.

The results reported here from research collaboration among the Malaŵi Department of Fisheries, the University of Malaŵi and the Malaŵi Ministry of Research and Environmental Affairs are a small but significant step in this direction and, perhaps, towards a reappraisal of what might succeed in sustainably increasing farmed fish production across subSaharan Africa. The projects undertaken by these partners date back to the Memorandum of Understanding signed between the Government of Malaŵi and ICLARM on 7 October 1986. Their work was subsequently supported very generously and continuously to October 1994 by the Bundesministerium für Wirtshaftliche Zusammenarbeit (BMZ) through the Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) GmbH, Germany.

ICLARM and its partners greatly appreciate this and are proud to have added, through German support, to a knowledge base that might help some of the disadvantaged farmers of subSaharan Africa. The opportunity to work with the GTZ and the dedicated efforts of all concerned, particularly the farmers and their families, who were our most important research partners, are also gratefully acknowledged.

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Director, Inland Aquatic
Resource Systems Program
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# Abstract

This volume reports the findings of the ICLARM-BMZ/GTZ Africa Aquaculture Project (1986-1994). The project studied smallholder farming systems and developed integrated aquaculture technologies in collaboration with the Malaŵian Department of Fisheries, the University of Malaŵi and the Ministry of Research and Environmental Affairs. The project began with a comprehensive survey of the ecological and socioeconomic context in which Malaŵian smallholding farmers must earn their living. The majority of the enterprises on these farms are resource-limited and use, for the most part, traditional farming methods which are increasingly unproductive and inadequate in light of expanding population pressure. One important consequence of the failure of traditional agriculture to meet human needs is environmental degradation associated with bringing marginal land into agriculture, and the overexploitation of fragile ecosystems.

To ameliorate this situation, technologies which could take advantage of existing on-farm resources to improve productivity and environmental sustainability were developed in on-station trials at the Malaŵi National Aquaculture Center. Suitable species from within the Malaŵian indigenous species flock were selected and their culture characteristics were described. Crop residues and weeds which could serve as fishpond inputs were identified. Methods for the use of fertile pond water and mud for vegetable production were devised. Integrated crop-fish and animal-fish systems which improved the profitability and productivity of the whole farm were designed. These technologies were demonstrated to extension agents and packaged into extension booklets for transfer to farmers.

Adoption of these technologies by smallholders using the existing extension approach and infrastructure was, however, less than was hoped for. To resolve this problem, farmers were approached directly for feedback. From their response, it became clear that more than just potential fish production was important in determining whether or not a particular farmer would adopt aquaculture. Among other things, the perceived ease with which fish culture could be inserted into the existing farming system was crucial. For example, adoption rates of rice-fish farming technology were much higher if the farmer had experience with either rice or fish.

The perceived simplicity (or potential risk) of the technology was also critical. If farmers were presented with a lot of details and options for maximizing fish production (e.g., oxygen cycling, role of pH, calculation of feeding rates and sampling protocols, etc.) during the initial introduction of fish farming, most farmers would not participate. Those who were presented only with the idea that a hole, filled with water and fed with wastes from other farm activities could produce some fish were much more likely to adopt the technology.

That farmers were more concerned about these issues than about the theoretical profitability of adopting aquaculture was a revelation to the researchers. It was previously assumed that a demonstrably better system of food production would be immediately adopted and that the constraints were largely related to the ability of the extension agents to explain, and farmers to grasp, complex ideas. In actual fact, the decisionmaking of farmers

is far more complicated than that. The project found that constraints to adoption were best dealt with by letting the farmers decide what technology they would like to use, regardless of its productivity relative to other technologies. In other words, the socioeconomic constraints to adoption of aquaculture (e.g., lack of investment capital and social leveling mechanisms) are exacerbated when extension agents and scientists attempt to impose technology on farmers.

To determine how farming systems evolved as a result of the adoption of fish farming, methods of participatory rural appraisal were adapted for use by researchers. This was combined with monitoring tools developed for farming systems research. This permitted the measurement of the impact of the integrated farming systems which were being promoted by the project and related extension programs. Profitability of farms participating in pilot studies was doubled, on average, and efficiency of production of vegetable gardens was improved. The simple systems which were adopted became more sophisticated and productive as the farmers became more familiar with fish farming.

To improve the technologies which were being presented to farmers and make these more immediately appropriate to their needs, a new set of research protocols was established. Rather than use an idealized optimal management strategy as a control of treatments, the actual types of materials available on smallholdings were applied in the amounts used by farmers. This dramatically reduced the productivity of the pond, but the amount of fish produced was much closer to what the farmers could realistically expect. Conducting research in this way forced scientists to interact with farmers during weekly visits and learn more about their constraints and perceptions. Scientists and farmers must communicate with each other if truly useful research is to be conducted and the results adopted by farmers.

# CHAPTER 1

## Introduction

In the late 1950s and early 1960s, development agencies began to promote small-scale fish farming in Africa as a means of improving the quality of life for poor farmers (Kalinga 1991). These early attempts to transplant into Africa technologies and systems developed elsewhere did not adequately consider local biological, agricultural or socioeconomic realities and therefore largely failed to achieve the hoped-for benefits (Costa-Pierce 1992c). The need for research and development specifically for African farmers was a primary justification for the establishment in 1986 of the ICLARM-BMZ/GTZ* Research for the Development of Tropical Aquaculture Technology Appropriate for Implementation in Rural Africa Project (Costa-Pierce 1990a, 1992c; Costa-Pierce et al. 1991).

In this initial project, technology development was aimed directly at problems faced by rural African smallholders, thus hopefully avoiding difficulties associated with trying to scale-down, or otherwise modify, foreign or more intensive technologies (Costa-Pierce 1990a, 1991a, b). The local availability of potentially useful bioresources and their efficiency as pond inputs was assessed. On-station studies were carried out at the Malaŵi National Aquaculture Center (NAC) to devise management strategies based only on these resources. Useful techniques were developed and presented to extension services for delivery to farmers and many publications were prepared for developing-country scientists and policy planners. Application of the technologies developed by the project increased average annual pond production in Malaŵi from 400-500 $kg \cdot ha^{-1}$ to 1,500-2,000 $kg \cdot ha^{-1}$ with no additional capital costs (Costa-Pierce and Pullin 1992). However, the rate of adoption of aquaculture technology remained low.

To investigate the reasons for the continued slow growth of rural fishfarming, GTZ in 1991 extended support for a second project phase entitled "Aquaculture Development in Africa: Learning from the Past and Implementing Research Results on Small-scale Farms". This funding was primarily for on-farm studies of factors affecting the adoption of the various technologies developed in the first project phase and the identification of any opportunities that may have been missed.

For this phase, ICLARM-BMZ/GTZ and its collaborators (the Malaŵian Department of Research and Environmental Affairs, University of Malaŵi and the Malaŵi Fisheries Department) adopted a systems approach, that is, the farm is viewed as a group of interdependent enterprises, in which resources flow from one enterprise to another, synergistically improving productivity and efficiency (Noble and Costa-Pierce 1992). The flow of resources is subject to socioeconomic as well as biotechnical constraints. Driving the system is the concept of integrated resource management: the farm as a whole is regarded as more than a sum of its constituent parts.

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* BMZ/GTZ: Bundesministerium für Wirstchaftliche Zusammenarbeit/Deutsche Gesellschaft für Technische Zusammenarbeit, GmbH.

In this approach, the fishpond is viewed, not as a stand-alone enterprise, but as a pivotal component in the whole farm ecosystem. In this way, the role and importance of aquaculture can be put into proper perspective. Data collected during this phase showed that a pond changes the whole ecology and economy of a farm, providing a wide range of services (water for irrigation and household use, fertile mud for improving garden soils, etc.) as well as producing fish. Also important is the pond's role as a bioreactor, converting low-value wastes and by-products into higher-value fish.

Studying smallholding farms and conducting research on-farm with this holistic orientation has led to the realization that technological appropriateness has as much to do with fitting new technologies into the existing farming system as it does with enhancing marginal productivity. By working on-farm, we have learned that small-scale African farming systems, rather than being simple as was assumed previously (largely because they utilized little modern technology), are complex and diverse. To accommodate this complexity, a new method of conducting aquaculture research and development was devised (Fig. 1.1). This approach integrates the farmer into the formulation of testable hypotheses and the experimental design. Rather than simply a receiver of technology, the farmer becomes an essential component of the experimental procedure. Trials indicate that technology developed in this way can spread from farmer to farmer more easily than packaged techniques which come onto the farm via traditional top-down extension (Chikafumbwa 1994a).

From the initial efforts to adapt aquaculture technology to the situation of the African smallholder, the project has evolved into a facilitation mechanism for the development of new technologies by and for the farmers themselves. Though still in the early stages, this approach to the development of technology and its transfer to farmers might help overcome some of the technical and sociocultural constraints to the adoption and dissemination of fishfarming in rural Africa. The documentation of this process should also provide insights into the complex ecology of rural African smallholding.

Since 1986, the project staff have conducted over 60 socioeconomic and biotechnical studies in the process of developing new technologies for use by rural smallholders. These have been formulated into an information kit for use by extension agents, research summaries for use by projects and regional scientists, and a wide range of peer-reviewed and other publications. Most of the results have been widely reported and are only summarized here; more detail is provided in previously unpublished data sets.

In addition to 115 publications and 75 national and international scientific presentations, the project has contributed substantially to the human and material resources available to the university system and the Malaŵi Fisheries Department. Twelve B.Sc. students from the University of Malaŵi have conducted their senior research topics with ICLARM-BMZ/GTZ support. Eight students have received M.Sc. degrees with financial and technical assistance from the project. Three more have completed, or are working on, Ph.D.'s with collaborative support from ICLARM-BMZ/GTZ. These people now occupy many of the midlevel and senior decisionmaking positions within the Malaŵian aquaculture community.

In addition, project staff taught 7 B.Sc.-level classes at the University of Malaŵi, conducted 22 training courses of varying length, presented 13 university seminars, held 3 major national and 2 international workshops, served as advisors to the National Agriculture Research System (NARS) and provided technical support for national and regional development projects (Noble and Lightfoot 1992, 1994; Chikafumbwa 1994b, c, d, e; Jamu 1994a, b; Jamu and Rashidi 1994; Janke et al. 1994; Kaunda 1994a, b; Kaunda and Janke 1994).

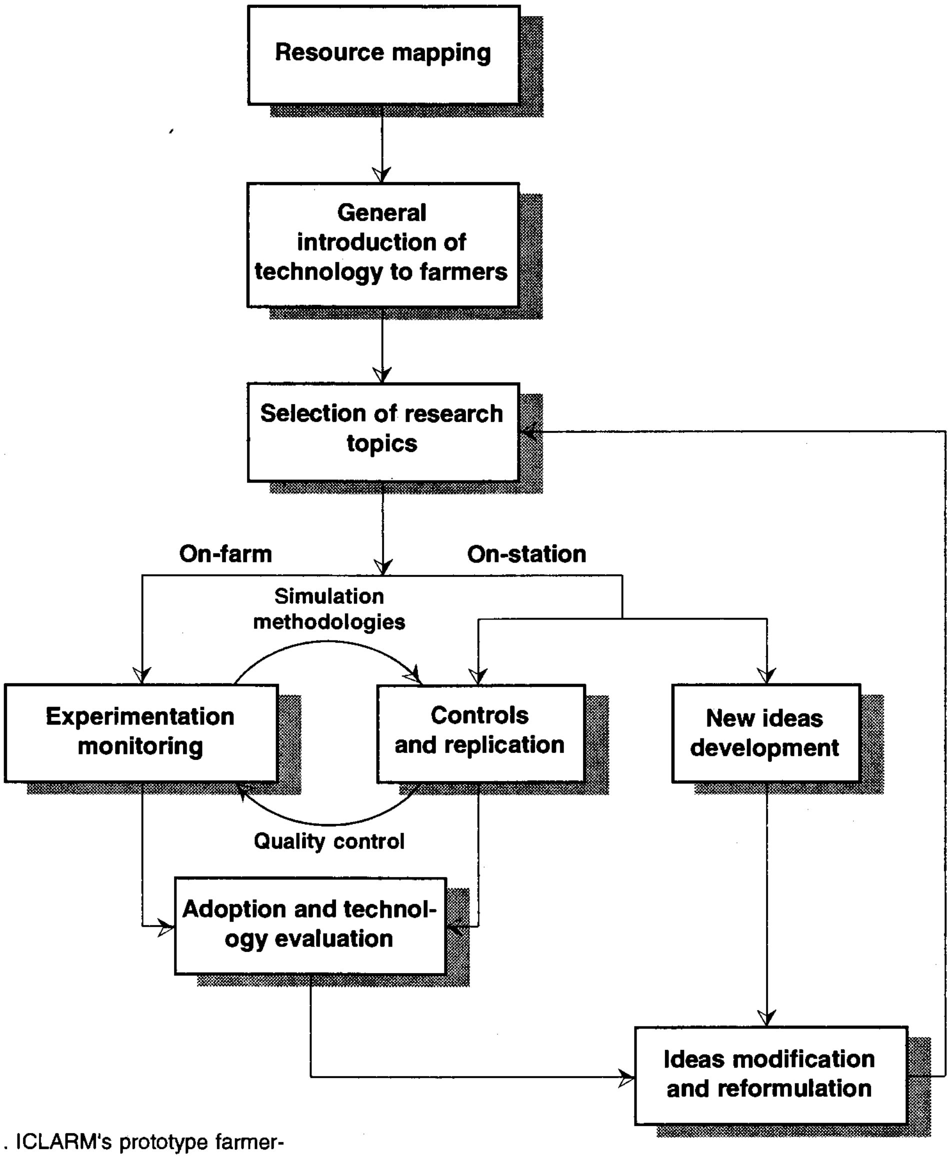


Fig. 1.1. ICLARM's prototype farmer-scientist partnership research and development methodology.

With ICLARM's acceptance into the Consultative Group on International Agricultural Research (CGIAR) in 1992, the research program has been expanded to cover other topics of strategic interest. ICLARM-BMZ/GTZ researchers have contributed substantially to this agenda with publications on aquatic biology (Costa-Pierce 1992b; Brummett 1995), experimental design (Kapeleta et al. 1991; Costa-Pierce et al. 1993a), development policies (Costa-Pierce 1991c; Brummett 1993a, b, 1994a; Lightfoot and Pullin 1994; Rashidi 1994), research protocols (Costa-Pierce 1990b; Lightfoot and Noble 1990; Noble and Kadangola 1990; Noble and Rashidi 1990; van Dam 1990a, b, c, 1991; Noble and Costa-Pierce 1991a, b; Noble 1994; Brummett and Noble 1995) and research techniques (Lightfoot 1991; Lightfoot et al. 1991; Noble et al. 1991; Lightfoot and Noble 1992, 1993; Brummett and Noble 1995).

# CHAPTER 2

# Smallholder Fishfarming in Malaŵi: Constraints and Potential

## Socioeconomic Constraints to Adoption of Aquaculture

The vast majority of subSaharan Africa's population are farmers who cultivate less than 5 ha. In Malaŵi, the average smallholding is 1.2 ha (ICLARM and GTZ 1990). Diverse crops are produced, most of which are consumed directly by the family or bartered within the community (Table 2.1). With current land use practices, 55% of these farmers are unable to produce enough to feed their families (Brummett 1994a, c).

Fishfarming, when integrated into the existing farming system, can increase the production and profitability of the smallholding (Chimatiro and Janke 1994). The cost of constructing and operating ponds is relatively low (Kandoole and Mkwezalamba 1991) but even so, out of the reach of many smallholders (ICLARM and GTZ 1990).

Poverty is not the only limiting factor in the uptake of integrated aquaculture technology. Important social constraints also exist (Likongwe 1991; Costa-Pierce and Pullin 1992). For example, Ng'ong'ola (1990a, 1991) found that 90% of farmers would eat fish grown in ponds fertilized with chicken or cattle manure, but only 66% would eat fish from a pig-manured pond and only 9% would eat fish from a human-manured pond. Lack of education about the nutritive value of fish leads many smallholders to discount the potential impact of a pond on their household and reduces adoption (Ayoade 1991). Mills (1991) found that mistrust of "the government" was reducing the effectiveness of extension efforts. Kishindo (1991) found that access to suitable land was the major constraint to pond construction.

Table 2.1. Major smallholding crops and the percentage of farmers who sell all, some or none into the cash economy (Ettema and Msukwa 1985).

| | Percentage of smallholders who sell: | | |
|---|---|---|---|
| | All | Some | None |
| Cassava | 0 | 33 | 67 |
| Sweet potato | 0 | 34 | 66 |
| Local maize | 0 | 34 | 66 |
| Improved maize | 38 | 43 | 19 |
| Rice | 0 | 31 | 69 |
| Peanuts | 1 | 48 | 51 |
| Pulses | 0 | 25 | 75 |
| Sugarcane | 1 | 39 | 60 |
| Bananas | 0 | 55 | 45 |

Ng'ong'ola (1990b, 1991), Kishindo (1991) and Harrison (1994) identified the matrilineal land-tenure system as a complicating factor in a farmer's decision to adopt fish culture. According to Harrison (1994), the instability of marriage in many rural African cultures exacerbates this problem. Men, who seem to do the majority of pond construction (Chiotha 1994) will be reluctant to make major capital improvements to land which reverts to the wife's family if the marriage dissolves.

### *Quality Extension*

Extension services which are not adequately financed and motivated can dramatically reduce the quality of technology transferred into rural communities and hence lower the rate of sustained adoption (Msiska 1991; Haight 1994; Kaunda 1994b; van den Berg 1994). This certainly has been the case for efforts to reach Malaŵian smallholders (Kalinga 1991). Weak extension services not only provide inadequate technical information. The approach of the agents can lead to misunderstandings between what the agent and the farmer expect from the fishpond (Harrison 1994). Mutambo (1991) felt that cultural differences between extension agents and villagers could also hinder development efforts.

There is a clear need for greater understanding of the role of aquaculture on small farms. Misunderstandings about pond ownership and household decisionmaking can lead extension agents into making incorrect assumptions about how the family can best be motivated to adopt fishfarming (Banda 1991). In a sample of 41 farms, Mills (1991) found that 61% were growing fish primarily for market and 39% primarily for household food. Males are more likely to take the lead in managing market ponds (Harrison 1994). Women and children play a larger role in managing ponds which produce mostly family food and may use the pond for other household management purposes such as laundry and dishwashing (Chiotha 1994). Although they may be attributed to the male during interviews, decisions about pond disposition and management are typically made collectively within the household and community (Mills 1991; Banda 1991). Banda (1991) also found that women play an important role in decisionmaking and this is not a result of the matrilineal land tenure system.

Whereas most ponds produce fish which are either eaten or sold, pond construction might be undertaken for purposes of claiming land or could be a way for individuals to improve their standing in the community, among other possible motivations (Mills 1991; Harrison 1994). If the extension agent assumes, for example, that the pond should be managed to maximize fish production for food or cash, his or her efforts might be in vain if the farmer is more interested in using the pond as a source of irrigation water.

Social constraints also affect the efficacy of farmer-to-farmer transfer of technology. Mills (1991) found that pond construction and management skills were considered to be difficult to obtain and were therefore regarded as commodities which affected social status and which were unlikely to be shared for free. Likongwe (1991) observed that farmer-to-farmer transmission was extremely important in the spread of information but was retarded in the presence of an active extension service.

### *Waterborne Diseases*

While seldom recognized as an issue for resource-poor farmers, questions have been voiced among the development community about possible increased incidence of waterborne and water-related vectorborne diseases as a result of pond construction. While the theoretical potential may be real, in southern Malaŵi, Chiotha and Jenya (1991) in a study of 25 ponds, and Chiotha (1994) in a study of 45 ponds, found only one and three ponds, respectively, which contained bilharzia-infected vector snails. Ayoade (1991) found no connection between the presence of a fishpond and the incidence of waterborne diseases in central Malaŵi. Apparently, ponds which are properly constructed and managed provide little shelter for vectors and are unlikely to pose public health threats (Chiotha 1994). Ponds which do pose health threats might be effectively cleansed of vectors through the use of indigenous plants (Chiotha et al. 1991; Msonthi 1991). These authors identified five effective molluscicidal species (*Diospyros usambarensis, Erythrophleum suaveolens, Phytolacca dodecandra, Talinum tenuissimum* and *Xeromphis obovata*), although the toxicity to humans of these plants when used in fishponds is still under investigation.

## Biotechnical Feasibility of Integrated Aquaculture

Essentially all agricultural enterprises on Malaŵian smallholdings are resource-limited (ICLARM and GTZ 1990; Noble and Chimatiro 1991b). Brummett (1994c) found that, for six major crops (maize, pulses, sorghum/millet, rice, peanuts and cotton) the difference by which production per hectare per year on experiment stations exceeds that on smallholdings averages 373% (Table 2.2). Fertilizers are used almost exclusively for improved maize varieties and rice, crops which are largely sold for cash and which are produced by fewer than 30% of smallholders. Brummett (1994c) estimated that only 27% of overall nitrogen requirements are being met with fertilizers. Data from Balarin et al. (1991) and Chikafumbwa et al. (1993), in which isonitrogenous pond-input regimes were compared to higher and lower energy diets, show that nitrogen is severely limited in smallholder ponds.

In such a resource-poor environment, fishpond productivity is, not surprisingly, well below maximum potentials. In 1985, total aquaculture output was estimated at 73 t from 170 ha of ponds, an average of only 430 kg·ha$^{-1}$ (Costa-Pierce and Pullin 1992). Technology extension can only increase productivity to a limited extent in these resource-limited systems. In a survey of 229 ponds, Noble and Chimatiro (1991b) found average standing stocks of 880 kg·ha$^{-1}$ in ponds averaging 366 m$^2$. From length-weight data, these authors determined that the most commonly cultured species, *Oreochromis shiranus*, was food-limited in these systems. Chikafumbwa (1990) and Kadongola (1990) found that doubling the amount of feed input to small ponds doubled yields of *T. rendalli, O. shiranus* and their polyculture.

Table 2.2. Average productivity of Malaŵian smallholding crops compared to output on estates and experiment stations (kg·ha·year$^{-1}$) (Manda et al. 1985).

| | Smallholder average | Realistic potential | Percentage difference |
|---|---|---|---|
| Maize | 2,800 | 6,250 | 123 |
| Pulses | 250 | 4,000 | 1,500 |
| Sorghum | 1,225 | 3,500 | 145 |
| Rice | 2,025 | 3,150 | 56 |
| Peanuts | 730 | 2,250 | 208 |
| Cotton | 660 | 2,000 | 203 |

Table 2.3. Smallholder resources (in kg·ha·year$^{-1}$) which might be used as fishpond inputs (Noble, in press; Noble and Costa-Pierce 1992).

| | |
|---|---|
| Maize stovers | 2,479 |
| Corncobs | 281 |
| Shucks | 181 |
| Maize bran (*madeya*) | 291 |
| Weeds | 5,822 |
| Wood ash | 600[a] |

[a] Per average household of 7.3 persons.

According to Noble and Chimatiro (1991a), the only materials on small farms which are not fully utilized are cooking fire ash and weeds. Another possible resource is maize bran (*madeya*) much of which is simply cast out or burned (Brummett 1994c). Noble (in press) identified several crop wastes (maize cobs, sheaths, stovers and bran), weeds, ash and livestock manures (albeit in very limited quantities) as potentially useful fishpond fertilizers, although they might have to be diverted from other productive enterprises (Table 2.3).

Most agriculture in Malaŵi is rainfed (ICLARM and GTZ 1990). Permanent water supplies tend to be located only in *dambo* (marshy channels which drain surrounding higher ground) and these areas are generally regarded as common-property by rural communities. The shortage of suitable land for fishpond construction was cited by Ng'ong'ola (1990b, 1991) as a major reason for failure to adopt aquaculture. This lack of widespread perennial water supplies has resulted in a preponderance of wealthier (albeit still quite poor) farmers, who tend to have access to more resources in general, being involved in fishfarming (Chimatiro and Janke 1994).

# CHAPTER 3

## Species for Aquaculture

Most smallholding fishfarmers grow various combinations of two indigenous tilapiine cichlids: *Oreochromis shiranus* and *Tilapia rendalli* (Noble and Chimatiro 1991b). Common carp (*Cyprinus carpio*) was grown on 21% of farms, up until a ban, implemented out of fear that escape from containment could cause serious harm to Malaŵi's endemic fish species, was imposed in 1992 (Msiska and Costa-Pierce 1993). Only 3% of farmers use other species (Chimatiro 1991). Research on the improvement of currently cultured species has focused on *O. shiranus* and *T. rendalli*.

The emphasis of ICLARM's aquaculture species research in Africa has been on indigenous, rather than exotic species (Msiska 1990; Jamu 1991b; Brummett 1993b; Jamu and Costa-Pierce, in press). With an estimated 1,000 endemic species in Malaŵi, opportunities exist to find species which should grow just as well as the most popular farmed exotic species in other countries and may even do better under local conditions. Research on the development of new species has focused on two indigenous planktivores: *Oreochromis karongae, Barbus paludinosus* and *B. trimaculatus*.

Following the ban of common carp, mentioned above, debate has continued on the need for fast-growing species. In traditional fishfarming logic, species which grow more rapidly should be preferred. This is definitely the case for fish destined for sale in markets where ready availability of cash is not a major limiting factor to volume of sales. In southern Malaŵian villages, however, cash is very much limiting with many families possessing no money at any particular time. Since marketing infrastructure is not available to move fish from the villages to urban centers, fish must be sold into this cash-poor market. Also, in Malaŵi and other southern African countries, consumers prefer whole fish to parts. This tradition makes the sale of processed fish, or the purchase and later division of a large fish problematic. Add this to the fact that fish are sold by weight with no premium paid by consumers for larger individuals and it becomes clear that criteria other than individual size might be used to make better management decisions.

Within a given set of conditions, a population of mixed-size fish will generally achieve a higher standing stock (by taking advantage of a wider range of available foods) than would a population composed of only one size of fish. This is especially true for the tilapias which feature a distinct set of ontogenetic shifts in their food preference. Since systems which do not require control of reproduction and/or grading of stock are inherently more flexible and easier to manage, and since there is no economic advantage to producing larger fish, biomass rather than individual growth rate has been the target of most of ICLARM-BMZ/GTZ's on-station species research.

## *Oreochromis shiranus*

By far the most widely cultured species in Malaŵi is the indigenous tilapia *O. shiranus* (Fig. 3.1). *O. shiranus* is a typical mouthbrooding tilapia and is in many respects very similar to *O. mossambicus* with which it shares home range in the lower Shire River valley. Like other commonly cultured oreochromiines, *O. shiranus* tends to reproduce while still relatively young in fishponds and rapidly reach carrying capacity with only a few individuals reaching a large size. Brummett and Noble (1995) evaluated gut contents of *O. shiranus* and found that they are highly omnivorous as juveniles, but change to a more specifically phytoplankton/ diatom-based diet at about 100 mm standard length (Table 3.1).

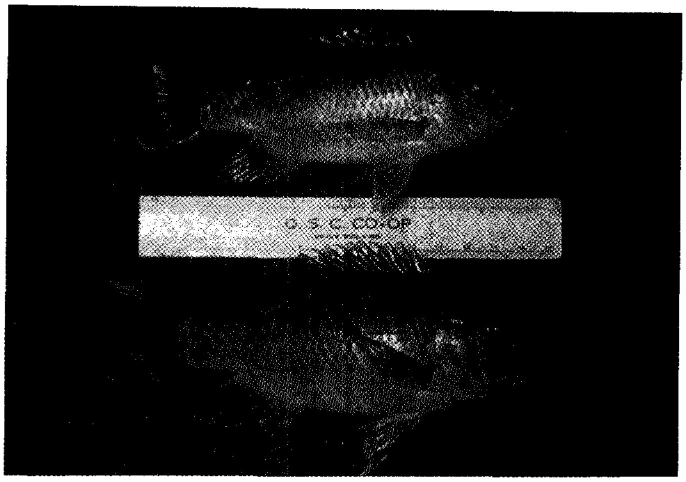


Fig. 3.1. *Oreochromis shiranus.*

Farm-based *O. shiranus* populations are easy to manage. They withstand high water temperatures, low dissolved oxygen and high ammonia concentrations. They are difficult to catch, even in small ponds, which makes them relatively less subject to poaching and predation than other species. They are easy to reproduce and hold in very small ponds, so availability of fingerlings is seldom a constraint. Being widespread and indigenous, new broodstock are readily available from the wild. The threat of inbreeding in small ponds is consequently reduced or easily remedied. Growth characteristics of *O. shiranus* under various culture conditions are shown in Table 3.2.

In Malaŵi, where fish play an extremely important role in human nutrition and where any size of fish is accepted in the market, *O. shiranus* is a good culture species. In fact, in a

Table 3.1. Stomach contents of *Tilapia rendalli, Oreochromis shiranus, Barbus paludinosus* and *B. trimaculatus* grown in ponds fed mixed weeds and maize bran (containing broken grain) at the Malaŵi NAC (Brummett and Katambalika 1994; Brummett and Noble 1994).

| | Size class SL (mm) | Diatoms | Other phyto-plankton | Micro-crus-taceans | Other zoo-plankton[a] | Detritus[b] | Maize endosperm | Others |
|---|---|---|---|---|---|---|---|---|
| *T. rendalli* | < 50 | 191 | 348 | 2 | 2 | 359 | + | |
| | 50-100 | 765 | 571 | 6 | 0 | 1,324 | ++ | |
| | >100 | 148 | 48 | 4 | 0 | 544 | + | |
| *O. shiranus* | <50 | 66 | 65 | 1 | 0 | 13 | + | |
| | 50-100 | 1,472 | 2,241 | 7 | 38 | 83 | ++ | |
| | >100 | 198 | 8,080 | 2 | 13 | 6 | +++ | |
| *B. paludinosus* | 50-60 | 1,058 | 874 | 51 | 13 | 46 | - | Insects |
| | 65-75 | 1,518 | 1,656 | 0 | 44 | 230 | +++ | |
| *B. trimaculatus* | 40-50 | 1,702 | 93 | 41 | 0 | 0 | + | |
| | 80-90 | 92 | 276 | 0 | 0 | 0 | ++ | Insects |

[a] e.g., rotifers, euglenoids, etc.
[b] Including macrophytic plant material.

Table 3.2. Growth of *Oreochromis shiranus* under various monoculture conditions.

| Inputs | Culture period (days) | Stocking rate (no.·$m^{-2}$) | Initial average weight (g) | Final average weight (g) | SGR[a] | Reference |
|---|---|---|---|---|---|---|
| *Madeya*[b] | 126 | 2.0 | 23.5 | 34.2 | 0.298 | Chikafumbwa et al. 1993 |
| *Madeya* + napier grass[c] | 126 | 2.0 | 24.1 | 41.3 | 0.428 | Chikafumbwa et al. 1993 |
| Napier grass[d] | 126 | 2.0 | 22.9 | 36.9 | 0.379 | Chikafumbwa et al. 1993 |
| Mixed[e] | 150 | 1.25 | 8.5 | 33.8 | 0.920 | Brummett and Katambalika 1994 |

[a] Specific growth rate (SGR) = $$\frac{\ln \text{weight}_{t2} - \text{Ln weight}_{t1}}{t2\text{-}t1} \text{ X } 100.$$

[b] 3% body weight per day.

[c] *Madeya* at 3% body weight per day + napier grass at 100 kg dry matter·$ha^{-1}$·$day^{-1}$.

[d] 100 kg dry matter·$ha^{-1}$·$day^{-1}$.

[e] Mixed diets are based on inputs used by farmers. They are mostly *madeya* with various combinations of chopped vegetable wastes. Total dry matter input averages 50 kg·$ha^{-1}$·$day^{-1}$.

survey of town and village markets, Brummett and Katambalika (in press) found that *O. shiranus* and other smaller tilapias are sold purely on the basis of weight. Since purchasing power in the villages is extremely low (Brummett 1994b), smaller individuals were easier to sell. The higher carrying capacity of small fish over large fish under smallholding fishpond conditions means that *O. shiranus*, which reproduce rapidly to increase total biomass (albeit at the expense of individual growth rate), serve the needs of farming families very well.

## *Tilapia rendalli*

*T. rendalli* (Fig. 3.2) is widespread and widely cultured in southern Africa. In Malaŵian fishponds, *T. rendalli* is a favored fish due to what local farmers feel is its superior flavor. Like *O. shiranus*, *T. rendalli* juveniles are omnivorous. Adults (in general, fish larger than 12-15 cm TL) favor macrophytic plant materials (Table 3.1).

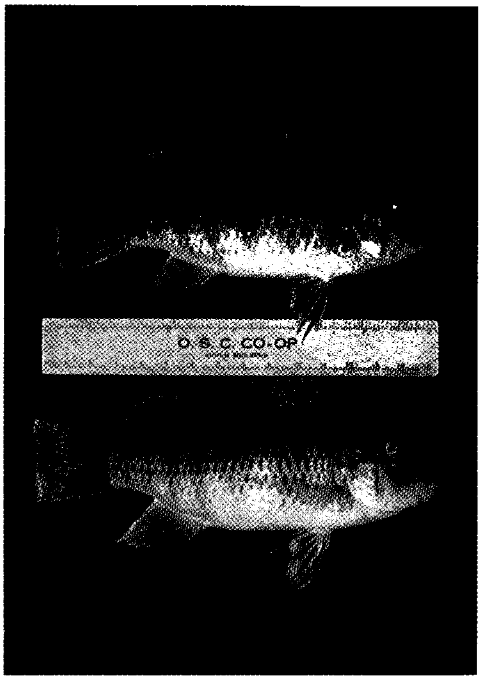


Fig. 3.2. *Tilapia rendalli.*

Brummett (1995) studied *T. rendalli* diets relative to their ability to take advantage of terrestrial and semi-aquatic weeds for growth. Weedy ponds stocked with *T. rendalli* adults (initial average weight = 48 g) produced the same amount of fish biomass as did ponds fed *madeya*, but eradicated all weeds within 120 days. Weedy ponds stocked with juveniles (initial average weight 4.6 g) produced significantly less fish biomass than did *madeya*-fed ponds and actually became weedier over the course of the study. Growth characteristics of *T. rendalli* under a variety of culture conditions are shown in Table 3.3.

Availability of broodstock and ease of reproduction are similar to *O. shiranus*. However, ease of capture by both fishers and birds makes *T. rendalli* less useful as a primary species in heavily predated smallholder ponds. In field trials, average survival of

Table 3.3. Growth of *Tilapia rendalli* under various monoculture conditions.

| Inputs | Culture period (days) | Stocking rate (no.·m$^{-2}$) | Initial average weight (g) | Final average weight (g) | SGR[a] | Reference |
|---|---|---|---|---|---|---|
| *Madeya*[b] | 126 | 2.0 | 21.9 | 34.8 | 0.368 | Chikafumbwa et al. 1993 |
| *Madeya* + napier grass[c] | 126 | 2.0 | 20.5 | 43.0 | 0.588 | Chikafumbwa et al. 1993 |
| Napier grass[d] | 126 | 2.0 | 20.8 | 35.5 | 0.424 | Chikafumbwa et al. 1993 |
| Mixed[e] | 119 | 1.0 | 47.8 | 69.0 | 0.308 | Brummett (unpubl.) |
| Rooted weeds[f] | 104 | 1.0 | 4.6 | 10.7 | 0.812 | Brummett (in press) |
| Mixed + rooted weeds | 119 | 1.0 | 47.3 | 65.2 | 0.270 | Brummett (unpubl.) |
| Improved[g] | 104 | 1.0 | 4.6 | 60.2 | 2.473 | Brummett (unpubl.) |
| Mixed (on-farm) | 191 | 1.0 | 6.7 | 48.7 | 1.039 | Noble (unpubl.) |

[a] Specific growth rate (SGR) = $\frac{\text{ln weight}_{t2} - \text{Ln weight}_{t1}}{\text{t2-t1}}$ X 100.

[b] 3% body weight per day.

[c] *Madeya* at 3% body weight per day + napier grass at 100 kg dry matter·ha$^{-1}$·day$^{-1}$.

[d] 100 kg dry matter·ha$^{-1}$·day$^{-1}$.

[e] Mixed diets are based on inputs used by farmers. They are mostly *madeya* with various combinations of chopped vegetable wastes. Total dry matter input averages 50 kg·ha$^{-1}$·day$^{-1}$.

[f] Ponds were left dry and allowed to fill with terrestrial weeds. Average standing crop of weeds at flooding = 91.3 g dry matter·m$^{-2}$.

[g] Improved diets were based on mixed diets in type of material but were used at a rate of 100 kg dry matter·ha$^{-1}$·day$^{-1}$.

*O. shiranus* was 67%, while only 30% of *T. rendalli* were still in the ponds after 85 days (Brummett and Chikafumbwa 1995).

## *Matemba*

*Matemba* is the vernacular for a flock of small *Barbus* species indigenous to southern Africa. The most common in southern Malaŵi are *B. paludinosus* (Fig. 3.3) and *B. trimaculatus* (Fig. 3.4). Both species are tolerant of a wide variety of environmental conditions, although *B. paludinosus* tends to be quite easily stressed when captured and handled. *B. trimaculatus* spends its entire life in streams, while *B. paludinosus* is more widely distributed in habitats which include lakes and marshes. *B. paludinosus* makes spawning migrations up local streams at the beginning of the rainy season.

Although both are extremely popular food fish in the region and command higher market prices than either *O. shiranus* or *T. rendalli* (Brummett and Katambalika, in press), little was known about their potential as aquaculture species.

To investigate this potential, several hundred mixed adult *matemba* were captured from the wild and placed in a 200 m$^2$ pond, just prior to the onset of the rainy season in the autumn of 1992. With the advent of the rains and the subsequent freshening of the pond, both species of *matemba*

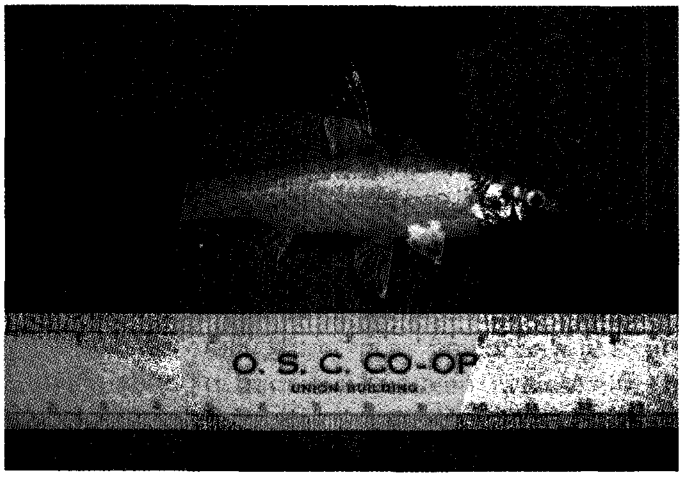


Fig. 3.3. *Barbus paludinosus*.

spawned prolifically. From the original stock of 335 fish were produced over 9,000 fingerlings. These (average weight 0.5 g) were split into six ponds and grown for 150 days. Final average weight for stocked fish was 6.8 g. Reproduction had occurred in the pond and fingerlings weighed an average of 2.6 g. Average standing stock at harvest was 775 kg·ha$^{-1}$. Gut content analysis revealed that the *B. paludinosus* were feeding primarily upon zooplankton while the *B. trimaculatus* were feeding on diatoms and detritus (Table 3.1).

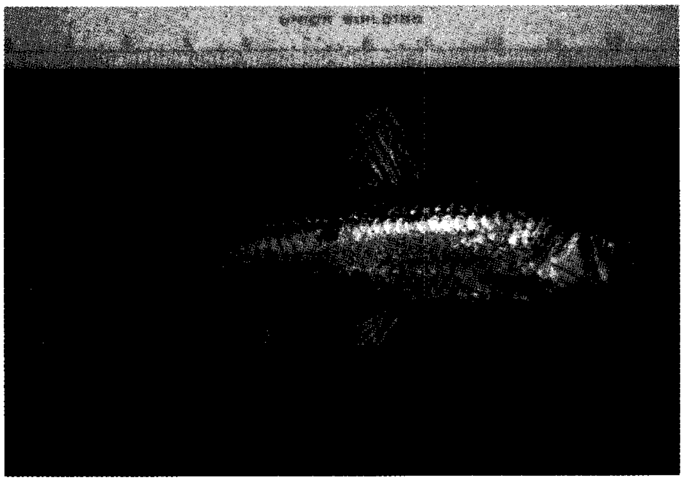


Fig. 3.4. *Barbus trimaculatus.*

Next, fingerlings of *B. paludinosus* and *B. trimaculatus* were stocked to evaluate the separate growth potentials for each species. *B. paludinosus* were stocked at 50,000 fish/ha (average weight at stocking = 2.5 g) and *B. trimaculatus* were stocked at 20,000 fish/ha (average weight at stocking = 5.4 g). After 150 days, *B. paludinosus* standing stock averaged 536.5 kg·ha$^{-1}$ (including 317 kg·ha$^{-1}$ of juveniles). After 107 days, *B. trimaculatus* standing stock at harvest averaged 537.5 kg·ha$^{-1}$ (including 411 kg·ha$^{-1}$ of juveniles). Results are summarized in Table 3.4.

Table 3.4. Stocking and harvest data for *matemba* monocultures. *Barbus paludinosus* treatments were stocked on 6 October 1993. *B. trimaculatus* treatments were stocked on 18 November 1993.

| | | Stocking | | Harvest | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | Stocked fish | | Juveniles | | Standing stock | |
| Treatment | Pond | No. (per 200 m$^2$) | Average (g) | No. (per 200 m$^2$) | Average (g) | No. (per 200 m$^2$) | Average (g) | Gross (kg·ha$^{-1}$) | Net (kg·ha$^{-1}$) |
| *B. paludinosus* | 10 | 1,000 | 1.89 | 763 | 7.5 | 1,400 | 2.3 | 520 | 426 |
| *B. paludinosus* | 14 | 1,000 | 3.31 | 448 | 8.0 | 4,143 | 1.8 | 525 | 360 |
| *B. paludinosus* | 44 | 1,000 | 2.21 | 299 | 8.5 | 6,872 | 1.3 | 565 | 454 |
| Average | | | 2.47 | 503 | 8.0 | 4,138 | 1.75 | 537 | 413 |
| *B. trimaculatus* | 13 | 400 | 6.63 | 191 | 10.0 | 2,583 | 3.0 | 483 | 350 |
| *B. trimaculatus* | 16 | 400 | 4.25 | 288 | 11.5 | 1,526 | 3.1 | 400 | 315 |
| *B. trimaculatus* | 18 | 400 | 5.25 | 200 | 12.0 | 12,200 | 1.0 | 730 | 625 |
| Average | | | 5.38 | 226 | 11.1 | 5,436 | 2.4 | 538 | 430 |

## *Oreochromis karongae*

The oreochromiine species in Lake Malaŵi are collectively known as *chambo*. One of these species, *Oreochromis karongae* (Fig. 3.5) was tested as an aquaculture candidate.

Initially, wild fish were collected from Lake Malaŵi, held and spawned in ponds at NAC. *O. karongae* showed strong seasonality in its onset of maturity and reproductive activity was strongly correlated with the onset of the rainy season. Fry production was very low.

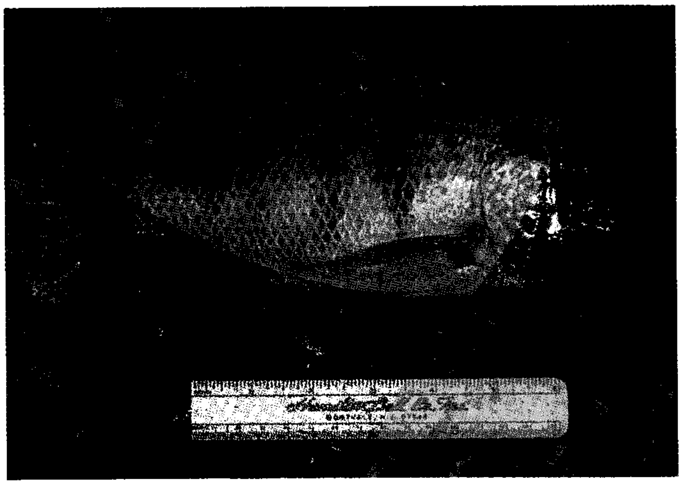


Fig. 3.5. *Oreochromis karongae*.

Individual growth at NAC (700 m elevation) was half that reported at 200 m elevation, but was still much faster than for any other species cultured in Southern Malaŵi.

To test these results under farm conditions, Maluwa (in press) and Noble (unpubl. data) stocked a 1:1 polyculture of *O. karongae* and *T. rendalli* into four ponds belonging to local fish clubs. Average pond size was 276.5 m$^2$. Fish were fed with *madeya* (maize bran) at a daily rate of approximately 60 kg·ha$^{-1}$ plus miscellaneous green materials at a rate of 7.5 kg·ha$^{-1}$. Fish were sampled every month and their growth rate charted (Fig. 3.6). *T. rendalli* performed significantly ($P<0.05$) better than *O. karongae* contributing, on average, 80% of standing stock at harvest, and appears to be the better species for smallholder fishfarming in Southern Malaŵi. Stocking and harvest data are summarized in Table 3.5.

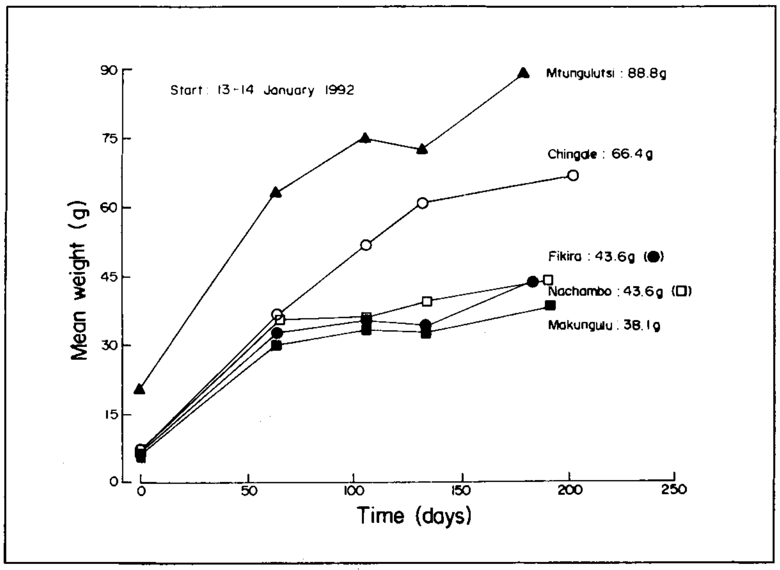


Fig. 3.6. *Oreochromis karongae* growth in farmponds in Southern Malaŵi (Noble, unpubl. data).

Coming from Lake Malaŵi, *O. karongae* is a relatively deepwater species compared to *O. shiranus* and *T. rendalli*, and this might account for the low rate of reproduction in shallow fishponds. Likewise, the low growth rate observed in farm trials might be the result of stress associated with low-quality inputs and/or shallow water.

Although not significantly more productive in smallholder fishponds than *O. shiranus* or *T. rendalli*, the relatively uniform size and better growth rate under better management has created interest in this species among potential commercial farmers. The Malaŵi Fisheries Department has therefore conducted a wider variety of trials on *O. karongae* than those reported here. Further information is available from: Fisheries Department, P.O. Box 700, Mzuzu, Malaŵi.

Table 3.5. Stocking and harvest data from a 194-day on-farm trial of *Oreochromis karongae* and *Tilapia rendalli* in polyculture on Southern Malaŵian smallholdings. Averages within column with different associated letters are significantly different ($P<0.05$)(Noble, unpubl. data).

| | | Stocking | | Harvest | | | |
|---|---|---|---|---|---|---|---|
| Fish club | Pond size ($m^2$) | Total no. | Average weight (g) | Stocked fish Total no. | Stocked fish Average weight (g) | Weight of reproduction (kg·ha$^{-1}$) | Standing stock (kg·ha$^{-1}$) |
| Chingale | 216 | | | | | | |
| *O. karongae* | | 216 | 6.6 | 50 | 66.4 | 0 | 153.6 |
| *T. rendalli* | | 216 | 7.4 | 186 | 47.6 | 39.2 | 449.1 |
| Nachambo | 259 | | | | | | |
| *O. karongae* | | 278 | 5.8 | 62 | 38.1 | 13.8 | 105.0 |
| *T. rendalli* | | 270 | 6.9 | 159 | 50.9 | 212.6 | 525.1 |
| Makungula | 181 | | | | | | |
| *O. karongae* | | 200 | 7.5 | 90 | 30.6 | 37.5 | 189.7 |
| *T. rendalli* | | 181 | 6.7 | 181 | 34.0 | 41.1 | 381.2 |
| Fikira | 360 | | | | | | |
| *O. karongae* | | 386 | 6.2 | 136 | 37.3 | 22.6 | 163.5 |
| *T. rendalli* | | 360 | 6.7 | 264 | 50.8 | 63.6 | 436.1 |
| Average | 276.5 | | | | | | |
| *O. karongae* | | 270 | 6.5a | 85a | 43.1a | 18.5a | 153.0a |
| *T. rendalli* | | 257 | 6.9a | 198b | 45.8a | 89.1b | 447.9b |

## *Cyprinus carpio*

Common carp (*Cyprinus carpio*) was introduced on a trial basis in the mid-1980s (Msiska 1993a). The justification for this was the perception that the available indigenous species were performing poorly in aquaculture (Mkoko and Mutambo 1993). ICLARM-BMZ/GTZ co-sponsored a conference at the Malaŵi NAC in September of 1991 to review the status and realized potential of common carp and discuss options for their future management (Msiska and Costa-Pierce 1993).

Common carp has been shown to have high individual growth rates when stocked at low densities (0.1-0.2 fish/m$^2$) in polyculture with *O. shiranus* (Msiska 1992; Noble 1993) although standing stocks at harvest were not significantly improved (averaging around 700 kg·ha$^{-1}$) over monoculture of *O. shiranus* (Noble 1993). Msiska (1993b) reported that the introduction of carp into fish production activities on tea estates actually reduced pond output.

Since purchasing power within rural communities is extremely low (Brummett 1994b), and since fish price is the same per unit weight regardless of individual fish size (Brummett and Katambalika 1994), maximizing the biomass of fish in the pond is of primary interest to both rural producers and consumers. In this context, the higher individual weights of common carp at harvest do not compensate for the lower overall production. Even if production is not reduced relative to *O. shiranus* monoculture (the fingerlings of which are produced *in situ*), the added expense of obtaining *C. carpio* fingerlings reduces profits.

Juxtaposed to the potential which carp might have in utilizing unused niches in the pond were concerns over the possible threat which carp might pose to Malaŵi's natural aquatic habitats and endemic fauna (Costa-Pierce 1992a). Costa-Pierce et al. (1993a) argued that carp could survive in littoral habitats of Lake Malaŵi and threaten endemic species diversity. Jamu (1993 et al.) pointed out that the performance of carp in Malaŵi cannot yet be said to justify the risks involved. In the end, the workshop voted 16-4 to ban the further use of common carp in Malaŵi.

## Polyculture

Polyculture can significantly improve pond productivity in cases where fish with complimentary diet preferences are cultured together. The traditional species mix on Malaŵian smallholdings is a polyculture of *T. rendalli* and *O. shiranus*. Based on the observation of Van Dam et al. (1990, 1993) that *T. rendalli* in grass-fed systems eats almost exclusively the grass while *O. shiranus* concentrates on natural pond food organisms, this polyculture ought to be more productive than the respective monocultures. Trials conducted by Brummett and Noble (1994), however, showed that under the mixed input regimes most commonly used by smallholders, the dietary habits of these two species in polyculture are quite similar and their polyculture does not significantly improve yields. This observation is supported by the findings of other researchers (Chikafumbwa 1990; Jamu 1990; Kadongola 1990; Chikafumbwa et al. 1993).

Another polyculture of species with similar dietary preferences tested at NAC by Brummett and Katambalika (in press), *O. shiranus* with *Barbus trimaculatus*, was likewise no more productive than the two monocultures (Table 3.6).

Polyculture of other species is more effective. Brummett and Katambalika (in press) found that growing *O. shiranus* (a phytoplanktivore) with *Barbus paludinosus* (a zooplanktivore) improved production by 40% over the *O. shiranus* monoculture (Table 3.7) and 140% over the *B. paludinosus* monoculture.

Pond productivity may not, however, be the best way to evaluate fish production systems. Brummett and Katambalika (in press) found that even though the *O. shiranus* + *B. trimaculatus* polyculture was more productive, it was only 16% more profitable than the *O. shiranus* monoculture (Table 3.8).

Table 3.6. Harvest data for a 107-day *Barbus trimaculatus-Oreochromis shiranus* polyculture study. Numbers in columns with different letters are significantly different ($P<0.05$).

| Treatment | Pond | *O. shiranus* | | | | *B. trimaculatus* | | | | Standing | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No. | Weight (kg) | Average (g) | Reproduction (kg) | No. | Weight (kg) | Average (g) | Reproduction (kg) | stock (kg) | Yield ($kg{\cdot}ha^{-1}$) |
| *O. shiranus* | 23 | 232 | 7.8 | 33.8 | 8.2 | | | | | 803 | 714 |
| *O. shiranus* | 28 | 204 | 7.8 | 38.2 | 6.9 | | | | | 736 | 634 |
| *O. shiranus* | 33 | 222 | 6.5 | 29.4 | 6.0 | | | | | 626 | 543 |
| Average | | 219.3a | 7.39a | 33.80a | 7.04a | | | | | 721.5a | 630.4a |
| Variance | | 134.22 | 0.37 | 12.82 | 0.84 | | | | | 5,356.17 | 4,919.35 |
| Polyculture | 15 | 184 | 6.3 | 34.0 | 5.6 | 188 | 2.6 | 13.8 | 3.5 | 895 | 728 |
| Polyculture | 17 | 192 | 5.7 | 29.7 | 6.7 | 339 | 3.4 | 9.9 | 3.6 | 970 | 762 |
| Polyculture | 43 | 175 | 5.7 | 32.3 | 4.3 | 248 | 1.9 | 7.5 | 0.9 | 635 | 496 |
| Average | | 183.7b | 5.87b | 31.98a | 5.54a | 258.33a | 2.60a | 10.40a | 2.66a | 833.5a | 661.8a |
| Variance | | 48.22 | 0.07 | 3.10 | 0.98 | 3,853.56 | 0.38 | 6.88 | 1.56 | 20,605.56 | 13,948.72 |
| *B. trimaculatus* | 13 | | | | | 191 | 1.9 | 10.0 | 7.8 | 483 | 350 |
| *B. trimaculatus* | 16 | | | | | 288 | 3.3 | 11.5 | 4.7 | 400 | 315 |
| *B. trimaculatus* | 18 | | | | | 200 | 2.4 | 12.0 | 12.2 | 730 | 625 |
| Average | | | | | | 226.3a | 2.53a | 11.14a | 8.22b | 537.5a | 430.0a |
| Variance | | | | | | 1,914.89 | 0.34 | 0.75 | 9.48 | 19,662.50 | 19,216.67 |

Table 3.7. Harvest data for a 150-day *Barbus paludinosus-Oreochromis shiranus* polyculture study. Numbers in columns with different letters are significantly different.

| Treatment | Pond | *O. shiranus* | | | | *B. trimaculatus* | | | | Standing stock (kg) | Yield (kg·ha$^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | No. | Weight (kg) | Average (g) | Reproduction (kg) | No. | Weight (kg) | Average (g) | Reproduction (kg) | | |
| *O. shiranus* | 7 | 219 | 9.6 | 43.9 | 8.2 | | | | | 893 | 777 |
| *O. shiranus* | 9 | 201 | 10.1 | 50.4 | 7.0 | | | | | 854 | 750 |
| *O. shiranus* | 45 | 227 | 8.7 | 38.2 | 6.0 | | | | | 733 | 633 |
| Average | | 215.7a | 9.47a | 44.1a | 7.1a | | | | | 827a | 720a |
| Variance | | 118.22 | 0.37 | 24.82 | 0.84 | | | | | 4,631.17 | 3,915.32 |
| Polyculture | 11 | 192 | 8.8 | 45.6 | 6.4 | 535 | 4.0 | 7.5 | 2.2 | 1,069 | 868 |
| Polyculture | 12 | 232 | 9.0 | 38.8 | 6.4 | 488 | 3.9 | 8.0 | 6.0 | 1,263 | 1,050 |
| Polyculture | 36 | 115 | 9.6 | 83.8 | 6.8 | 371 | 3.2 | 8.5 | 5.5 | 1,250 | 1,099 |
| Average | | 179.7a | 9.13a | 56.06a | 6.50a | 464.7a | 3.69a | 7.99a | 4.56a | 1,165.5b | 1,005.5b |
| Variance | | 2,357.56 | 0.14 | 393.03 | 0.03 | 4,754.89 | 0.15 | 0.17 | 2.77 | 7,838.54 | 9,945.18 |
| *B. paludinosus* | 10 | | | | | 763 | 7.3 | 9.5 | 3.2 | 520 | 426 |
| *B. paludinosus* | 14 | | | | | 448 | 3.4 | 7.3 | 7.3 | 525 | 360 |
| *B. paludinosus* | 44 | | | | | 299 | 2.7 | 9.0 | 8.6 | 565 | 454 |
| Average | | | | | | 503.33a | 4.40a | 8.59a | 6.33a | 536.5c | 413c |
| Variance | | | | | | 37,413.56 | 4.12 | 0.93 | 5.36 | 391.51 | 1,559.68 |

Table 3.8. Local market value of tilapia (*Oreochromis shiranus*) and *matemba* (*Barbus paludinosus* and *B. trimaculatus*) produced under monoculture and polyculture in 1994, Malaŵi kwacha (US$1 = Malaŵi kwacha 7). The values indicated for juveniles are the total number produced less the number needed for restocking.

| System | Tilapia | | *Matemba* | | Total |
|---|---|---|---|---|---|
| | Adult | Juvenile | Adult | Juvenile | |
| Tilapia monoculture (150 days) | 79.80 | 7.40 | - | - | 87.20 |
| Tilapia/*B. paludinosus* polyculture | 63.70 | 5.50 | 37.00 | 7.05 | 113.25 |
| *B. paludinosus* monoculture | - | - | 44.00 | 13.65 | 57.65 |
| Tilapia monoculture (107 days) | 62.30 | 7.80 | - | - | 70.10 |
| Tilapia/*B. trimaculatus* polyculture | 41.30 | 4.70 | 26.00 | 5.40 | 77.40 |
| *B. trimaculatus* monoculture | - | - | 25.00 | 21.15 | 46.15 |

## Fry Production

### *Oreochromis shiranus*

The production of adequate numbers of *O. shiranus* fingerlings for distribution to the growing body of fishfarmers has been a major component of the Government of Malaŵi's aquaculture extension effort (Noble and Chimatiro 1991a). Research has focused on methods which could be adopted by smallholders, rather than on systems which maximize numbers of seed but might only be useful to larger-scale commercial operations. In preliminary studies of the reproductive biology of this species, Maluwa (1990) and Maluwa et al. (in press) observed that, like many members of the genus *Oreochromis*, *O. shiranus* can mature at smaller sizes (6-8 g) in fishponds than in the wild, particularly when fed low-quality feeds, although the variability for this trait is high and some fish may still be immature at 53 g. Half of females were mature by 12 g and males by 16 g.

Maluwa (1991) found 17°C to be critical to gonadal maturation in *O. shiranus* and maximum fry production only achievable at temperatures above 20°C. Monitoring of fry production over 413 days showed that *O. shiranus* only spawns when the daily minimum temperature exceeds 17°C, regardless of daily high (Maluwa and Costa-Pierce 1993).

These authors also found that, in 3 x 3 x 1 m hapas stocked at a sex ratio of 1 male: 2 females (average weight of females at stocking = 42 g) and 0.7, 1.0 or 1.7 broodfish per $m^2$, total fry production was significantly ($P<0.05$) higher over 203 days (harvested every three weeks) at the 1.7 and 1.0 fish per $m^2$ densities (4,969 and 4,259, respectively) than at 0.7 fish per $m^2$ (2,980) when brooding females were returned to the hapas (Fig. 3.7).

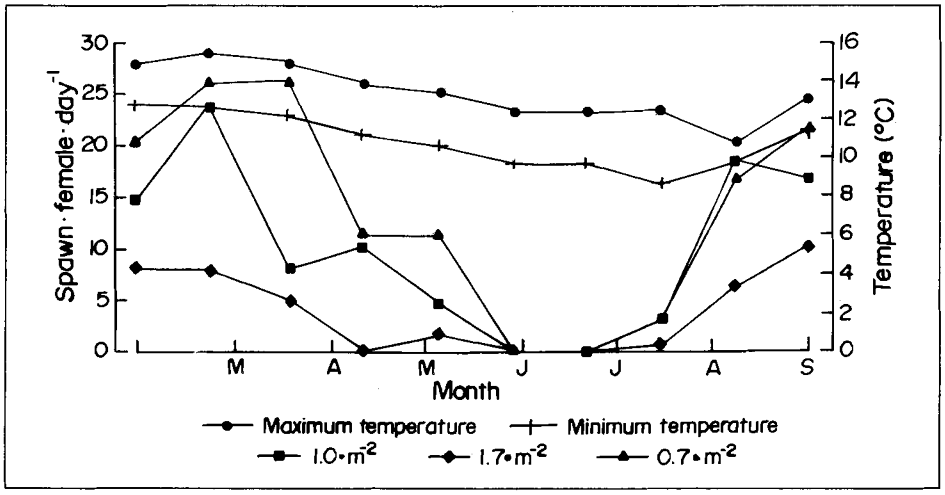


Fig. 3.7. Fry production from *Oreochromis shiranus* stocked at a sex ratio of one male: two females in 3 x 3 x 1 m hapas at three densities.

Under similar conditions for 169 days, removing sac-fry and eggs from females for incubation produced significantly ($P<0.05$) more seed (8,363) at 1.7 broodfish per $m^2$ than at 1.0 or 0.7 broodfish per $m^2$ (6,625 and 6,096, respectively). Removal of eggs and sac-fry reduced the harvest of free-swimming fry to an average of 2,415 fry per hapa (no significant difference between treatments). If these data can be accurately scaled down, it appears that a single 1 $m^2$ hapa stocked at with one male and two females could produce enough *O. shiranus* fry to render the typical Malaŵian smallholder self-sufficient in seed. The feasibility of this approach is supported by the finding of Ambali (1990) that hapa size was not a constraint in conditioning tilapia broodstock.

Farmers with more capital and/or brood ponds can produce substantial numbers of seed from simple facilities. In unpublished results of practical trials conducted at NAC in nine 3 x 3 x 1 m hapas equally divided among three 200 $m^2$ ponds and harvested every three weeks, nine 42 g males and eighteen 34 g females (1 male and 3 females per $m^2$) produced an average of 2,058 large fry (average weight 0.3 g) per hapa over 133 days (Table 3.9). As was the case for Maluwa and Costa-Pierce (1993), temperature was a major regulator of *O. shiranus* reproduction in this study as well.

Table 3.9. *Oreochromis shiranus* fry production from 3 x 3 x x m hapas stocked 6 January 1993 with one male and two females. Overall fry production = 0.9·female·day$^{-1}$. Temperature becomes critical around mid-May.

| Pond | Hapa | 2 Feb | 4 Mar | 19 Mar | 4 Apr | 28 Apr | 19 May | 133-day total |
|---|---|---|---|---|---|---|---|---|
| 10 | 1 | 253 | 500 | 580 | 357 | 180 | 123 | 1,993 |
| | 2 | 100 | 418 | 525 | 675 | 231 | 86 | 2,035 |
| | 3 | 201 | 500 | 360 | 60 | 351 | 31 | 1,503 |
| Subtotal | | 554 | 1,418 | 1,465 | 1,092 | 762 | 240 | 5,531 |
| 11 | 4 | 76 | 350 | 464 | 804 | 387 | 42 | 2,123 |
| | 5 | 107 | 601 | 585 | 942 | 621 | 145 | 3,001 |
| | 6 | 97 | 421 | 498 | 1,578 | 462 | 75 | 3,131 |
| Subtotal | | 280 | 1,372 | 1,547 | 3,324 | 1,470 | 262 | 8,255 |
| 12 | 7 | 120 | 327 | 417 | 204 | 183 | 162 | 1,413 |
| | 8 | 115 | 267 | 291 | 176 | 615 | 354 | 1,818 |
| | 9 | 91 | 425 | 354 | 336 | 249 | 53 | 1,508 |
| Subtotal | | 326 | 1,019 | 1,062 | 716 | 1,047 | 569 | 4,739 |
| Grand total | | 1,160 | 3,809 | 4,074 | 5,132 | 3,279 | 1,071 | 18,525 |

A study conducted by Mhango and Brummett (unpubl. data) compared male: female sex ratios of 1:1 and 1:3 at a fixed stocking density of 1.25 fish per m$^2$ (either 125 or 187 females per pond) in six 200 m$^2$ ponds. Males averaged 112 g and females averaged 95 g in individual weight. Swim-up fry production per pond and per female were highly variable over 70 days (each pond was seined weekly) and final values were not significantly different between the two treatments (Table 3.10, Fig. 3.8). Swim-up fry production averaged 14,050 fry per pond from the 1:1 treatment and 12,200 fry per pond from the 1:3 treatment. Fry per female averaged 112 at the 1:1 sex ratio and 65 at the 1:3 sex ratio. From these data, there is clearly no advantage to risking inbreeding by using higher sex ratios in brood ponds. If nursing ponds are available to grow swim-up fry to stockable size (approximately 10 g), one fingerling producer operating with three 200 m$^2$ ponds could theoretically supply 70 typical smallholders.

In reality, losses of both fry and broodfish to various predators substantially reduce seed production in the field. An on-farm fingerling production trial found that a 180 m$^2$ pond stocked with 60 males (average 58 g) and 120 females (average 35 g) produced 736 fingerlings of various sizes ranging from 2 to 25 g over 296 days (Brummett and Chikafumbwa 1995). At final harvest, it was discovered that all of the original broodfish had disappeared at some point.

### *Tilapia rendalli*

*T. rendalli* is a popular food fish and is commonly stocked with *O. shiranus* in smallholder ponds. *T. rendalli* fry production in ponds is generally lower than for *O. shiranus* and is often insufficient to restock ponds after harvest. Methods which might be useful for semi-specialized private-sector fry producers have been investigated. Brummett (unpubl. data) found that average *T. rendalli* fry production from 200 m$^2$ ponds (N=2) stocked with 100 males (average 50 g) and 100 females (average 39 g) was 2,738 fry (average weight 1 g) over 138 days (Fig. 3.9). A peak in fingerling production occurred one month after stocking and then declined due largely to decreasing temperatures.

Table 3.10. Fry production from 200 m$^2$ earthen ponds stocked with 150 *Oreochromis shiranus* at a male: female sex ratio of either 1:1 or 1:3 to test the hypothesis that *O. shiranus* reproduction in ponds is limited by the number of females. Ponds were fertilized every 14 days with 20 kg·ha$^{-1}$ of diammonium phosphate. Ponds were seined weekly to collect fry. (See also Fig. 3.8).

| Treatment | Pond | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | Total |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 male : 1 female | 39 | 0 | 200 | 800 | 2,600 | 1,000 | 300 | 3,000 | 2,000 | 2,500 | 800 | 750 | 13,950 |
|  | 40 | 500 | 150 | 300 | 2,000 | 1,200 | 1,000 | 3,500 | 500 | 600 | 2,500 | 500 | 12,750 |
|  | 42 | 600 | 500 | 1,500 | 2,000 | 1,000 | 900 | 3,000 | 500 | 700 | 2,000 | 2,200 | 14,900 |
| 1 male : 3 females | 37 | 0 | 0 | 1,500 | 2,500 | 1,000 | 250 | 2,000 | 400 | 500 | 1,000 | 500 | 9,650 |
|  | 38 | 0 | 0 | 1,000 | 2,400 | 500 | 200 | 2,500 | 600 | 1,500 | 1,600 | 800 | 11,100 |
|  | 41 | 1,000 | 2,500 | 1,500 | 1,000 | 1,500 | 1,100 | 2,000 | 1,500 | 800 | 1,500 | 2,000 | 16,400 |
| Total |  | 2,100 | 3,350 | 6,600 | 12,500 | 6,200 | 3,750 | 16,000 | 5,500 | 6,600 | 9,400 | 6,750 | 78,750 |

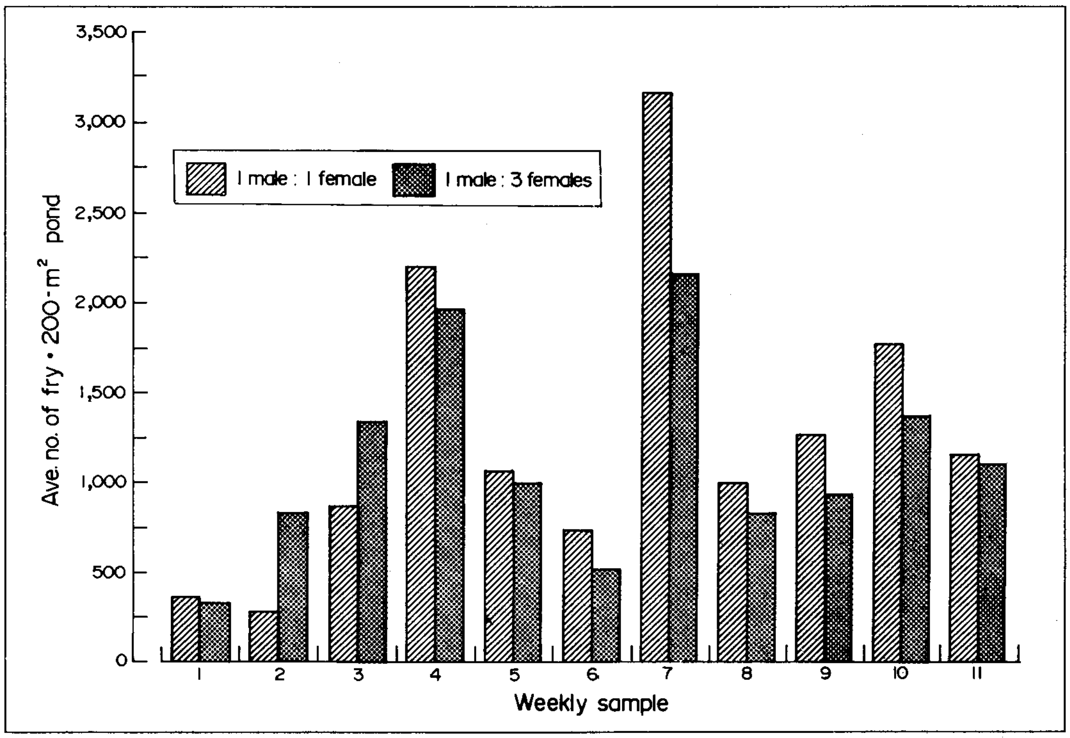


Fig. 3.8. *Oreochromis shiranus* fry production in 200 m$^2$ ponds stocked with 1:1 or 1:3 male to female sex ratio at 1.25 fish·m$^{-2}$.

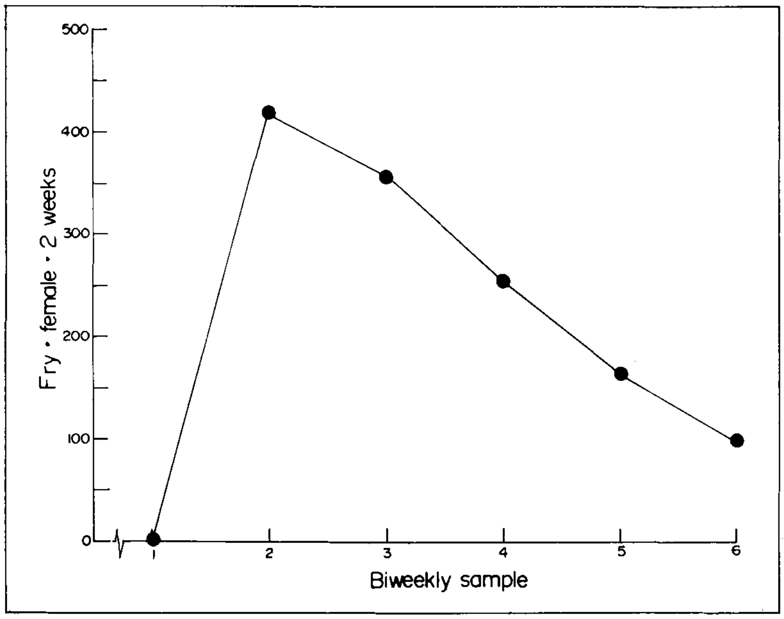


Fig. 3.9. *Tilapia rendalli* production from 200 $m^2$ earthen ponds stocked with one male and one female per $m^2$.

In tanks and hapas, Costa-Pierce (in press) found that *T. rendalli* fry production was an order of magnitude lower than that for *O. shiranus*. Fry production was highest at a male:female broodstock ratio of 1:1 and was not affected by the presence or absence of natural substrate upon which to build nests.

Most potential fry producers (i.e., those farmers with access to perennial water supplies) possess only one or two small ponds and no nets for removing seed. From these systems, it is necessary to harvest fingerlings which are large enough to distribute directly to ongrowers without a fry-rearing phase, and which can be captured with locally available technology. Recent trials at NAC using a reed fence to capture fingerlings compared two harvesting cycles (30 and 60 days). When 200 $m^2$ ponds stocked with 100 males (average 59 g) and 100 females (average 46 g) were partially harvested every 30 days (after an initial 60 days) an average (N = 3) of 4,978 fingerlings (average weight = 4.5 g) could be produced

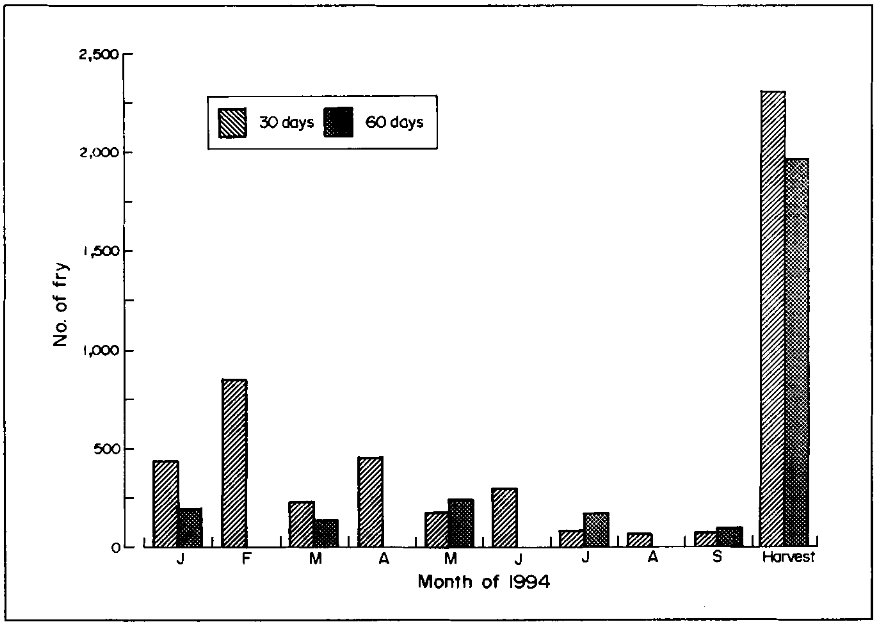


Fig. 3.10. *Tilapia rendalli* production in 200 $m^2$ earthen ponds stocked with one male and one female per $m^2$ in 1994.

over a 9-month period. When partially harvested every 60 days, an average of 2,807 fingerlings (average weight = 6.3 g) were collected (Fig. 3.10). Production was depressed during the colder months of July, August and September. A good percentage of total fingerling production was collected at final draining, presumably the result of cumulative escapement from the reed fence.

# CHAPTER 4

# Improved Pond Management Systems

With few high-quality materials available for use as smallholder pond inputs, the marginal economic impact of low-quality by-products and simple methods for increasing the efficiency of nutrient use, such as pond turbation and partial harvesting, might be higher than on wealthier farms. Since pond productivity will be limited by poor soils (Williams 1989) and lack of food (Chikafumbwa 1990; Kadongola 1990), overall increases in fish production will only be achieved through more widespread adoption of aquaculture (Noble and Chimatiro 1991a; Noble and Costa-Pierce 1992). Management options which take advantage of local resources are needed.

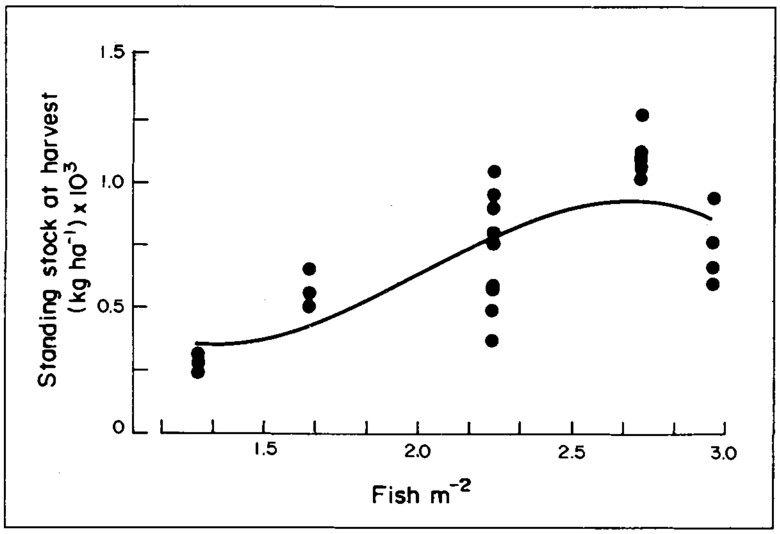
## Fish Stocking Rates

Stocking rates in smallholder ponds are generally constrained by the proximity and availability of fingerlings and/or transportation. Stocking rate also interacts strongly with the species used and the availability of pond inputs to affect productivity. By examining stocking and harvest data from farmer cooperators and experiment station trials, Brummett (unpubl.) identified a general trend in pond output relative to stocking rate (Fig. 4.1). From this analysis, it appears that carrying capacity for smallholder fishponds is typically about 1,000 $kg \cdot ha^{-1}$. Under these constraints, standing stock at harvest of various mixtures of *O. shiranus* and *T. rendalli* fed different materials at different rates will tend to increase with stocking rates up to about 25,000 fish per hectare.

In general, under a fixed set of environmental conditions, polycultures of *O. shiranus* and *T. rendalli*, as managed by Malaŵian smallholders, will most often produce maximal standing stocks when stocking at rates of more than 20,000 fish per hectare and less than 30,000 fish per hectare. The most economical stocking rate would probably be closer to the lower, rather than the upper, limit.

## Pond Inputs

Fish production on Malaŵian smallholdings is nutrient-limited. Even in the best managed ponds, carrying capacities are seldom greater than 1,000 $kg \cdot ha^{-1}$. Kapeleta et al. (1991) and Costa-Pierce et al. (1993a) performed multiple regression analyses to determine which factors were most important in regulating *O. shiranus* and *T. rendalli* production in Malaŵian smallholder ponds. Of the environmental factors which are manageable by farmers, they identified inputs and dissolved oxygen as the two of key importance.



N' th order $Y = A + Bx + Cx^2 + Dx^3$

Constant = 33.0354
1 degree coefficient = -0.2933029
2 degree coefficient = 1.009475E-03
3 degree coefficient = -9.610045E-07

$R^2$ = 0.5191
Multiple correlation = 0.7205

ANOVA for prediction F = 8.277
Chance probability P = 0.0006

Std. error of estimate = 4.2335
Variance of estimate = 17.9224

Degrees of freedom = 3 and 23

Fig. 4.1. Stocking rate vs. standing stock at harvest extrapolated from a compilation of 24 station and field trials in Southern Malaŵi.

Table 4.1. Fish yields, costs and incomes associated with the use of various smallholder resources in integrated agriculture-aquaculture in Southern Malaŵi.

| Input | Input rate | Mean yield (kg·ha$^{-1}$·year$^{-1}$) | Range | Cost of input (US$) | Income (US$) |
|---|---|---|---|---|---|
| Napier grass | 100 kg DM·ha$^{-1}$·day$^{-1}$ | 1,405 | 647 - 2,195 | 14.58 | 34.00 |
| Maize bran | 3% MBWD | 1,726 | 406 - 2,368 | 2.65 | 41.77 |
| Napier grass/maize bran | As above | 3,013 | 2,726 - 3,299 | 17.23 | 82.70 |
| Waste pumpkin leaves[a] | 50 kg DM·ha$^{-1}$·day$^{-1}$ | 1,444 | 1,372 - 1,616 | 12.60 | 35.06 |
| Maize stover compost/FWA[b] | 3% MBWD; 2.5 t·ha$^{-1}$ | 750 | 710 - 790 | 7.38 | 18.20 |
| Smallholder farmers using maize bran | When available | NA | 400 - 500 | 2.65 | 10.89 |
| Smallholder farmers using maize bran | When available | 951 | 241 - 3,336 | 2.65 | 23.01 |

[a] Cost of waste pumpkin leaves based on labor input to harvest waste leaf.

[b] FWA - fuelwood ash and agricultural limestone combination.

Notes:

NA - data not available.

MBWD - mean body weight per day.

1. Cost of fresh fish, 1991 retail prices @ US$1.21.
2. Cost of maize bran @ US$0.04·kg$^{-1}$ dry matter @ 10% moisture.
3. AL - agricultural limestone @ US$0.04·kg$^{-1}$.
4. FWA - no cost; a waste resource from household cooking fires.
5. Cost of maize compost based on labor input @ US$0.81/day to construct compost heap; purchase of bamboos for pile aeration @ US$0.13/bamboo.
6. Napier grass cost based on labor input to cut grass @ US$0.81/day.
7. Costs of inputs are: kg·year$^{-1}$·200-m$^2$ pond (2 fish crops·year$^{-1}$; 1-ha pond).
8. Income is per 200-m$^2$ pond (2 fish crops·year$^{-1}$; 1-ha pond).

Noble and Chimatiro (1991a) surveyed smallholdings in the Southern Region of Malaŵi and identified a variety of materials which might be used as pond inputs (Table 4.1). Some of these are almost completely unused on the farm while others have competing uses and must be weighed against these prior to using the materials in the fishpond.

### *Wood Ash*

Of the materials available on-farm, wood ash is abundant (548 kg for a family of five per year) and has few, if any, alternative uses (Noble, in press). Jamu (1990, 1991c)

Table 4.2. Chemical characteristics of firewood ash (FWA) compared to agricultural limestone ($CaCO_3$) (Jamu and Costa-Pierce 1993).

| % | FWA | $CaCO_3$ |
|---|---|---|
| Neutralizing value | 79.8 ± 1.4 | 118.0 ± 2.1 |
| Total carbonates | 53.8 ± 0.3 | 94.0 ± 1.0 |
| Nitrogen | 0.06 | 0.0 |
| Orthophosphate (ppm) | 10.2 ± 0.5 | 0.0 |
| Total phosphorus | 2.1 ± 0.02 | 0.0 |
| Potassium | 7.5 ± 0.1 | 0.2 |
| Magnesium | 2.7 ± 0.1 | 0.9 ± 0.1 |
| Calcium | 29.9 ± 0.3 | 35.7 ± 0.1 |
| Sodium | 0.4 ± 0.01 | 0.2 ± 0.01 |

Notes:
Mean of three replicates.
Standard deviation values which are so small as to be insignificant are not shown.

compared ash from maize stover, rice straw, wild grass (*Rottboelia exaltata*) and wood as possible low-cost alternative liming agents for Malaŵian smallholders (Table 4.2). Wood ash had the highest neutralizing value (79.8%) compared to grass ash (53.3%), maize stover ash (44.0%) and rice straw ash (29.2%). In a laboratory study, Jamu (1991a) observed that wood ash applied at a rate of 3 $t \cdot ha^{-1}$ could raise the pH of pond water from 7.45 to 9.57 and total alkalinity from 14.6 $mg \cdot l^{-1}$ as $CaCO_3$ to 34.4 $mg \cdot l^{-1}$ over 20 days. When applied to ponds, organic matter destroys alkalinity and reduces pH. Jamu (1991a, c) found that, at application rates in excess of 50 $kg \cdot ha^{-1} \cdot day^{-1}$ dry matter, pH in concrete tanks was reduced by an average of 2.39 units over 91 days. Through an application of 0.75 tons per hectare of wood ash, pH in these systems could be kept above 7.5, even if dry matter application rates increased to 300 $kg\ ha^{-1} day^{-1}$.

Firewood ash, either by direct contribution, or by increasing pH and so reducing the P-binding capacity of the soils, also serves as an important source of phosphate in low-input systems (Jamu and Costa-Pierce 1993). Jamu (1990) measured phosphorus content of firewood ash to be 0.001% and found that an application of 750 $kg \cdot ha^{-1}$ significantly ($P<0.05$) raised chlorophyll *a* content in concrete tanks from 2.87 $\mu g \cdot l^{-1}$ to 14.22 $\mu g \cdot l^{-1}$. Jamu and Costa-Pierce (1993) measured 13.5% and 23.7% increases in orthophosphate over one hour in 500 l tanks receiving 1.5 and 3.0 $t \cdot ha^{-1}$, respectively, of firewood ash.

In fish production trials, Jamu and Msiska (in press) tested a 2.5 $t \cdot ha^{-1}$ initial application of a 60:40 combination of agricultural limestone and wood ash on production of a 1:1 polyculture of *O. shiranus* and *T. rendalli* stocked at 1.5 fish per $m^2$ in 200 $m^2$ ponds and fed with 3% of body weight maize stover compost. Lime/ash increased production to 434 $kg \cdot ha^{-1}$ from 276 $kg \cdot ha^{-1}$ with compost alone. Jamu and Costa-Pierce (1993) found that pure firewood ash increased the effectiveness of maize stover applications (Table 4.3).

Table 4.3. Water quality and growth of a 1:1 polyculture of *Oreochromis shiranus* and *Tilapia rendalli* under three input regimes.

| Treatment | Total phosphorus (± 1 SD) | Total alkalinity (± 1 SD) | Soil pH (± 1 SD) | Water pH (± 1 SD) | SGR (%/day) (± 1 SD) |
|---|---|---|---|---|---|
| Control[a] | 0.4 ± 0.1a | 6.5 ± 1.7a | 6.13 ± 0.19a | 7.08 ± 0.23b | -0.12 ± 0.36a |
| FWA[b] | 0.9 ± 0.1a | 59.2 ± 14.3b | 6.69 ± 0.23b | 8.16 ± 0.20c | 0.11 ± 0.23a |
| Maize stover[c] | 0.7 ± 0.2b | 14.0 ± 1.4a | 5.54 ± 0.34a | 6.66 ± 0.18a | 0.93 ± 0.22b |
| FWA/maize stover[d] | 0.6 ± 0.2b | 68.3 ± 9.0b | 6.92 ± 0.04b | 7.27 ± 0.15b | 1.12 ± 0.57b |

Notes:
Values in column followed by the same letter are not significantly different ($p < 0.05$).
[a] No inputs.
[b] FWA - firewood ash at 1.5 $t \cdot ha^{-1} \cdot week^{-1}$.
[c] Maize stover compost at 100 kg dry $matter \cdot ha^{-1} \cdot day^{-1}$.
[d] A combination of firewood ash and maize stover compost at the above rates.

### *Madeya*

Maize bran (*madeya*) is the highest quality by-product potentially available for fish production (Table 4.4) and has been recommended as a pond input to Malaŵian farmers since the 1940s and is used by 90% of fishfarmers (Fig. 4.2). *Madeya* has alternative uses on farms, primarily as poultry feeds and Mills (1991) reported that conflicts arose in 31% of families regarding its use as a pond input. On the other hand, Brummett (1994b) reported large quantities of *madeya* simply being burned in the Southern Region and 86% of farmers interviewed by Kadongola (1990) indicated it as being "available" or "readily available" as pond inputs.

Kadongola (1990, 1991), in tests conducted in concrete tanks, estimated the optimal feeding rate of *madeya* to a 1:1 polyculture of *T. rendalli* and *O. shiranus* as 5% of body weight per day. Unfortunately, this rate exceeds the amount of *madeya* available on the average smallholding (Noble, in press). While not maximizing growth rates, feeding *madeya* at 3% body weight per day is practical for most all smallholders. Kadongola (1990), feeding this rate to a 1:1 polyculture of *T. rendalli* and *O. shiranus* stocked into 200 $m^2$ ponds at a rate of 20,000 fish per hectare, reported a significant ($P<0.05$) increased carrying capacity from 371 $kg{\cdot}ha^{-1}$ to 976 $kg{\cdot}ha^{-1}$ (Table 4.5).

Table 4.4. Proximate analyses of common materials which could be used as fishpond inputs in Southern Malaŵi.

| Scientific name | Common name | Part used | DM$^a$ | Composition as a % of dry matter<br>CP$^b$ | CF$^c$ | Ash | EE$^d$ | NFE$^e$ |
|---|---|---|---|---|---|---|---|---|
| *Zea mays* | *Madeya* | Bran | 93.0 | 2.1 | 8.0 | 3.0 | 13.8 | 72.3 |
| *Zea mays* | Maize | Stover | 89.5 | 6.3 | 30.9 | 14.6 | 1.6 | 46.6 |
| *Manihot* spp. | Cassava | Leaves | 16.5 | 25.9 | 20.6 | 8.1 | 5.6 | 42.3 |
| *Ipomoea batatas* | Sweet potato | Leaves | 10.8 | 19.4 | 10.2 | 25.9 | 3.7 | 40.8 |
| *Leucaena leucocephala* | *Leucaena* | Leaves | 30.9 | 21.0 | 18.1 | 8.4 | 6.5 | 46.0 |
| *Rottboellia exaltata* | Buffalo bean | Grass | 22.0 | 11.1 | 32.9 | 10.9 | 2.3 | 42.8 |
| *Echinochloa pyramidalis* | Antelope grass | Leaves | 82.5 | 7.0 | 31.4 | 8.6 | 1.1 | 51.9 |
| *Pennisetum purpureum* | Napier grass | Whole plant | 22.0 | 10.2 | 32.9 | 13.4 | 1.8 | 42.8 |
| *Morus nigra* | Mulberry | Leaves | 38.3 | 17.6 | 7.4 | 20.4 | 11.5 | 43.1 |
| *Amaranthus* spp. | Amaranthus | Whole plant | 19.0 | 19.9 | 21.0 | 17.0 | 1.5 | 40.6 |
| *Musa paradisica* | Banana | Leaves | 94.1 | 9.9 | 24.0 | 8.8 | 11.8 | 45.5 |
| *Carica papaya* | Pawpaw | Leaves | 22.1 | 26.8 | 10.9 | 13.2 | 7.7 | 42.0 |
| *Hyparrhenia rufa* | Giant grass | Leaves | 30.0 | 6.0 | 31.3 | 15.5 | 2.1 | 45.8 |

$^a$DM - dry matter.
$^b$CP - crude protein.
$^c$CF - crude fiber.
$^d$EE - ether extract.
$^e$NE - nitrogen-free extract.

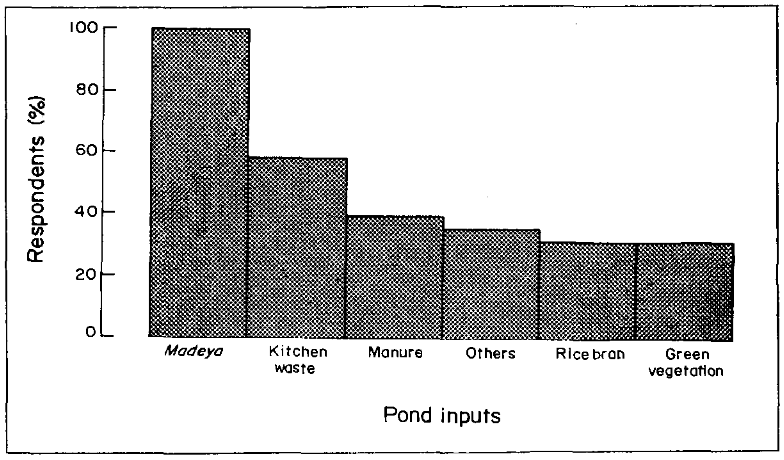


Fig. 4.2. Types of fishpond inputs used by a sample of 29 smallholders in Southern Malaŵi (Kadongola 1990).

Table 4.5. Growth and production of *Oreochromis shiranus* (OS), *Tilapia rendalli* (TR) and their 1:1 polyculture in 200 $m^2$ earthen ponds for 126 days fed napier grass at a rate of 100 kg $ha^{-1} \cdot day^{-1}$ dry matter, maize bran at 3% of body weight per day or a combination of the two. The combination of inputs was used as a cumulative rate, that is, 100 kg dry matter of napier grass + 3% body weight of maize bran per day.

| Treatment | Stocking | | | Harvest | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of fish per pond | Mean initial weight (g) | | Mean final weight (g) | | % weight gain | | % fish survival | | Extrapolated[a] net yield ($kg \cdot ha^{-1} \cdot year^{-1}$) | % recruits contribution to net yield | SGR (% $day^{-1}$) | |
| | | TR | OS | TR | OS | TR | OS | TR | OS | | | TR | OS |
| Monoculture TR | | | | | | | | | | | | | |
| Napier grass | 400 | 20.8 | - | 35.5 | - | 70c | - | 93 | - | 2,303 (2,126-2,584) | 76 | 0.42a | - |
| Napier grass/maize bran | 400 | 20.5 | - | 43.0 | - | 94b | - | 87 | | 2,598 (2,393-3,277) | 65 | 0.52a | - |
| Maize bran | 400 | 21.9 | - | 34.8 | - | 61c | - | 89 | - | 1,585 (1,332-1,767) | 63 | 0.37a | - |
| Monoculture OS | | | | | | | | | | | | | |
| Napier grass | 400 | - | 22.9 | - | 36.9 | - | 59c | - | 85 | 1,657 (1,241-2,275) | 70 | - | 0.37a |
| Napier grass/maize bran | 400 | - | 24.1 | - | 41.3 | - | 72b | - | 96 | 2,149 (1,761-2,523) | 69 | - | 0.42a |
| Maize bran | 400 | - | 23.5 | - | 34.2 | - | 46d | - | 79 | 1,069 (731-1,587) | 65 | - | 0.32a |
| Polyculture TR/OS | | | | | | | | | | | | | |
| Napier grass | 400 | 22.0 | 21.1 | 41.7 | 36.4 | 89b | 71b | 67 | 89 | 1,405 (929-1,964) | 63 | 0.51a | 0.41b |
| Napier grass/maize bran | 400 | 22.8 | 17.4 | 46.9 | 41.9 | 106a | 140a | 97 | 78 | 3,013 (2,703-3,425) | 67 | 0.57a | 0.69a |
| Maize bran | 400 | 22.4 | 19.0 | 41.4 | 33.1 | 85b | 67b | 97 | 83 | 1,726 (1,291-2,542) | 72 | 0.49a | 0.39b |
| No input | 400 | 21.0 | 18.6 | 21.4 | 22.5 | 2d | 21e | 71[b] | 74[b] | -184 (-242-168) | 100[b] | 0.01b | 0.15c |

[a] Net yield is extrapolated from 200 $m^2$ ponds over 126 days.

[b] Total final weight-total initial weight was negative for fish stocked.

Kadongola (1990) noted that cooking or further finely grinding *madeya* had no effect on production of *T. rendalli* or *O. shiranus.*

### *Weeds*

Weeds are another commonly available and underused farm resource (Table 4.4). Noble (in press) measured weed biomass in maize fields and found them to contain an average of 1,248 kg of dry matter per hectare. Most of this material is simply burned off. Using weeds productively as pond inputs could increase profits while reducing seasonal air pollution.

Chikafumbwa et al. (1991a) found that *T. rendalli* and *O. shiranus* will directly consume a wide variety of the weeds available in Malaŵian farms. Of 29 weeds tested, 23 were eaten by *T. rendalli* and 6 by *O. shiranus.* The plant species preferred by *O. shiranus* were, in order of preference: *Ipomoea batatas, Cucurbita maxima, Tridax procumbens, Biden pilosa, Carica papaya* and *Mucuna pruriens. T. rendalli* was much less particular and consumed at least 50% of 15 out of 29 plant species presented. The six plant species which were not touched by either species were: *Tehprosia vogelli, Cassia obtusifolia, Ludwigia erecta, Vernonia petersii, V. cinerea* and *Tithonia diversifolia.*

Brummett (1995) found that, in *T. rendalli,* there is a distinct ontogenetic shift from omnivory to the consumption of leafy plant materials which occurs around 12-15 cm TL. In this study, ponds were allowed to fill with terrestrial weeds and were then flooded and stocked with 200 *T. rendalli* adults (initial average weight = 48 g) or juveniles (initial average weight 4.6 g). Adults ate 100% of weeds in 120 days (final average weight = 65 g) while ponds stocked with juveniles actually became weedier (average weight at harvest = 11 g).

Napier grass (*Pennisetum purpureum*) is widely available in Southern Malaŵi. Chikafumbwa (1990) found that 62% of farmers had sufficient napier grass to use it as a dry-season pond input. Chikafumbwa (in press) fed chopped napier grass to monocultures of 400 mixed sex *T. rendalli* and *O. shiranus* stocked in 200 $m^2$ earthen ponds and found that it produced as much biomass as did *madeya,* the most common material used by Malaŵian smallholders. Van Dam et al. (1990, 1993) measured *T. rendalli* + *O. shiranus* polyculture carrying capacity at 670 $kg{\cdot}ha^{-1}$ in 200 $m^2$ ponds fed napier grass at a daily rate of 100 $kg{\cdot}ha^{-1}$ dry matter (Table 4.5).

Maximum growth rates of *O. shiranus* and *T. rendalli* fed napier grass were achieved at application rates of 100 kg dry matter per day in 5 $m^3$ cement tanks and 200 $m^2$ earthen ponds. *O. shiranus* performed 35% better on average than *T. rendalli* under all culture conditions (Chikafumbwa and Costa-Pierce 1991).

In cement tanks, Chikafumbwa (1990) reported no differences between growth of *O. shiranus* when fed with whole, chopped or ground napier grass. *T. rendalli,* however, grew better on either whole or chopped napier grass.

Chimatiro (1991) and Chimatiro and Costa-Pierce (in press) reported yields of 1,444 $kg{\cdot}ha^{-1}{\cdot}year^{-1}$ (compared to 1,726 $kg{\cdot}ha^{-1}{\cdot}year^{-1}$ for *madeya*) from a 1:1 polyculture of *O. shiranus* and *T. rendalli* fed waste pumpkin leaves at a daily rate of 50 $kg{\cdot}ha^{-1}$ dry matter. Waste cabbage leaves produced yields of 678-1,024 $kg{\cdot}ha^{-1}{\cdot}year^{-1}$.

Green plant materials also act as pond fertilizers so their use is not restricted to culturing fish which eat them directly (Costa-Pierce et al. 1993a). Green weeds are moderately fibrous with crude fiber contents of 15-30% and nitrogen contents of 2-4%. Such herbaceous materials break down readily in shallow ponds compared to high-fiber materials like maize stover and straw (see Composting below). For example, Jamu (unpubl. data) found that 2.0 m long x 0.5 m diameter bundles of napier grass broke down within 30 days when scattered around the bottom of 60-cm deep ponds.

### *Maize Stover*

Composting offers opportunities to utilize materials which are otherwise of little value as pond inputs. Such by-products as maize stovers, shucks, corncobs and rice straw, while widely available on smallholdings (Jamu 1990; Noble, in press), break down very slowly and have very little nutritive value to *O. shiranus* when placed directly in ponds (Jamu 1990). As these materials contain very little nitrogen, their decomposition in the pond can actually remove dissolved nitrogen from the pond water in the short term. Composting of nutrient-poor materials is therefore best accomplished outside the pond.

Maize stover compost, applied at a rate of 100 kg·ha$^{-1}$ dry matter per day produced specific growth rates in a 1:1 *O. shiranus/T. rendalli* polyculture (4 fish/m$^2$ in 5 m$^3$ concrete tanks) of 0.93 % per day (Jamu and Costa-Pierce 1993).

### *Mixtures of Inputs*

Mixed input regimes are not only the most common among smallholders, but might also make better use of available pond inputs, particularly for polycultures. Noble and Costa-Pierce (1992) reported a three-fold increase in production from ponds fed mixtures of *madeya* and napier grass compared to ponds fed *madeya* alone.

Chikafumbwa et al. (1991b) found that a mixed pond input regime of *madeya* and chopped napier grass (*P. purpureum*), a common species in fallow *dambo*, increased carrying capacity of a 1:1 polyculture of *T. rendalli* and *O. shiranus* stocked into 200 m$^2$ ponds at a rate of 20,000 fish per hectare, significantly ($P<0.05$) increased carrying capacity from 976 kg·ha$^{-1}$ to 1,432 kg·ha$^{-1}$ although it had no effect on either *T. rendalli* or *O. shiranus* monocultures (Table 4.5). This seems to indicate that polycultures of these two species are synergistically utilizing the mixed input regimes to improve pond productivity.

Mixtures of maize stover compost and wood ash improved production of a 1:1 polyculture of *O. shiranus* and *T. rendalli* (Jamu and Costa-Pierce 1993) over wood ash alone, but not over maize stover compost alone (Table 4.3).

Chikafumbwa et al. (1993) and Balarin et al. (1991) found that isonitrogenous (700 g nitrogen/ha/day) combinations of wood ash, *madeya*, napier grass and urea, produced the same amount of growth in a 1:1 polyculture of *O. shiranus* and *T. rendalli* stocked at two fish per m$^2$ as did *madeya* alone, at lower overall cost (Table 4.6).

## Pond Stirring

Resuspending nutrients which have been removed from the water column, particularly those which have settled into anaerobic muds, might permit their utilization by phytoplankton and consequently improve fish productivity (Costa-Pierce and Pullin 1989; Williams 1989). Manual pond stirring was tested in 200 m$^2$ ponds by Costa-Pierce (1991) to measure its impact on a 1:1 polyculture of *O. shiranus* and *T. rendalli* (Table 4.6). Raking the pond bottom twice per week increased total alkalinity, electrical conductivity and total hardness

Table 4.6. Growth and production of a 1:1 polyculture of *Oreochromis shiranus* (OS) and *Tilapia rendalli* (TR) in 200 $m^2$ earthen ponds for 126 days under a range of isonitrogenous (0.7 kg $N \cdot ha^{-1} \cdot day^{-1}$ ) input regimes (Chikafumbwa et al. 1993).

| Treatment | Stocking | | | Harvest (112 days) | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | No. of fish per pond | Mean initial weight (g) | | Mean final weight (g) | | % weight gain | | % fish survival | | Extrapolated[a] net yield ($kg \cdot ha^{-1} \cdot year^{-1}$) | % recruits contribution to net yield | SGR (% $day^{-1}$) | |
| | | TR | OS | TR | OS | TR | OS | TR | OS | | | TR | OS |
| Urea (U) | 100 | 47.1 | 51.1 | 63.5 | 65.9 | 35bc | 31bc | 63 | 66 | 404 (221-575) | 47 | 0.27bc | 0.24bc |
| Maize bran (MB) | 100 | 42.9 | 50.4 | 76.5 | 94.6 | 79a | 88a | 91 | 82 | 1,940 (1,365-2,315) | 72 | 0.52a | 0.56a |
| Napier grass (NG) | 100 | 42.8 | 53.5 | 85.6 | 86.6 | 100a | 62ab | 92 | 79 | 1,230 (1,203-1,257) | 57 | 0.51a | 0.43a |
| Wood ash (WA) | 100 | 41.3 | 49.5 | 55.0 | 60.1 | 33c | 21c | 58 | 57 | 266 (185-358) | 37 | 0.26c | 0.17c |
| Stirring (S) | 100 | 42.7 | 50.9 | 54.5 | 55.3 | 28c | 9c | 55 | 55 | 182 (168-196) | 58 | 0.13c | 0.12c |
| MB/NG/WA[b] | 100 | 42.5 | 49.9 | 77.4 | 87.8 | 82a | 76a | 81 | 85 | 592 (535-649) | 28 | 0.36b | 0.55a |
| U/MB/NG/WA[b] | 100 | 41.3 | 49.1 | 75.7 | 83.7 | 83ab | 71a | 60 | 57 | 2,075 (1,709-2,442) | 83 | 0.44ab | 0.52a |
| S/U/MB/NG/WA[b] | 100 | 42.0 | 49.7 | 77.8 | 89.9 | 85a | 81a | 73 | 74 | 1,950 (1,731-2,168) | 76 | 0.45ab | 0.52a |
| S/MB/NG/WA[b] | 100 | 50.6 | 51.4 | 73.8 | 77.5 | 46b | 51b | 76 | 76 | 2,442 (2,247-2,730) | 93 | 0.34b | 0.37b |
| No input | 100 | 48.1 | 53.1 | 57.1 | 66.2 | 19c | 25c | 64 | 61 | 295 (175-415) | 61 | 0.15c | 0.20c |

[a] Net yield is extrapolated from 200 $m^2$ over 112 days.

[b] Isonitrogenous combination of inputs.

but reduced dissolved oxygen and specific growth rates of stocked fish (Kapeleta et al. 1991; Costa-Pierce et al. 1993a). Total standing stock was, however, increased in stirred ponds due to increased reproduction and/or survival of fry. Net yields from the stirred ponds were 1,874-2,249 kg·ha$^{-1}$ after 112 days, of which 76-93% were composed of fry/fingerlings. In unstirred ponds, net yields ranged from 684 to 1,924 kg·ha$^{-1}$ of which 28-83% were fry/fingerlings.

## Appropriate Harvesting Technologies

The lack of harvesting mechanisms has been cited as a major constraint to the adoption of fishfarming in Malaŵi (Ayoade 1991). Kaunda (1991a, b) and Kaunda and Costa-Pierce (1993) investigated the use of two traditional fish capture technologies, hook and line and plunge baskets (Figs. 4.3 and 4.4), for harvesting *O. shiranus* and *T. rendalli* polyculture ponds. Success with hook and line was highly variable, but seemed to be more effective in deeper water. Plunge baskets were generally more efficient but required that the water be lowered to no more than 30 cm to be effective. Overall, the instantaneous rate of removal was 0.7-27.7% for hook and line and 28-39% for plunge baskets.

A further trial (Kaunda and Costa-Pierce 1993) tested a "reed fence" (Fig. 4.5) constructed of split *bangu* reeds (*Phragmites mauritianus*) joined together with stems of *chilambe* (*Helichrysum chrysophorum*), a common creeper. The reed fence is moved slowly through the pond by a team of six to eight men in a manner similar to the working of a seine net. Once corralled, the fish are lifted out with small dip nets made of mosquito-netting on a split bamboo frame. The reed fence, when pulled five to six times through a 200 m$^2$ pond, managed to remove 36% of both *O. shiranus* and *T. rendalli*. Harvesting with a typical seine net resulted in a 92% removal of *O. shiranus* and 33% removal of *T. rendalli*.

### *Partial Harvesting*

Partial harvesting systems might overcome the necessity of removing all the fish from the pond while increasing overall yield. Brummett (unpubl. data) compared the hook and line, basket traps (Fig. 4.6) and reed fence in their effectiveness in managing *O. shiranus*

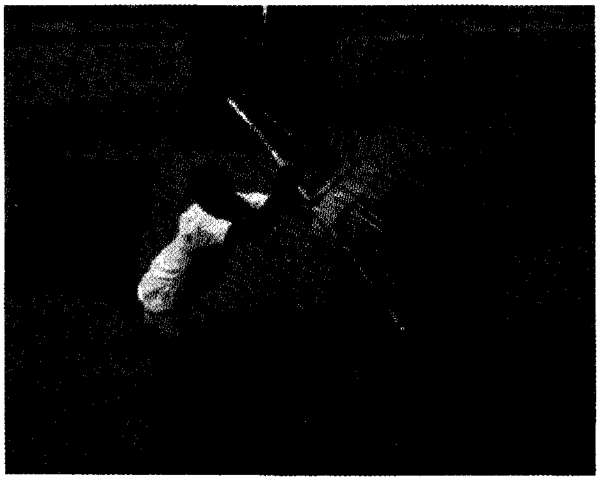


Fig. 4.3. Plunge basket.

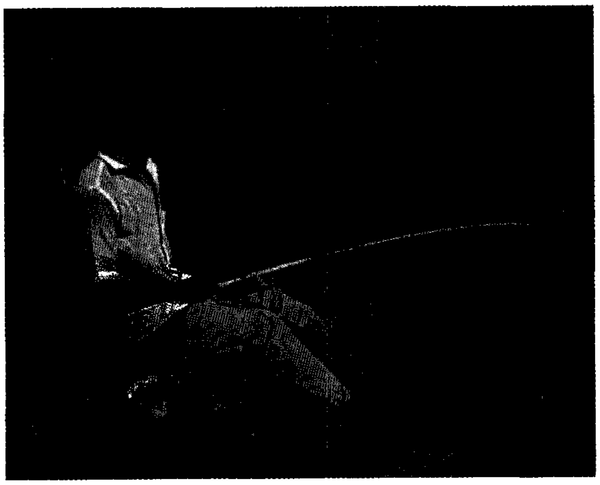


Fig. 4.4. Hook and line fishing.

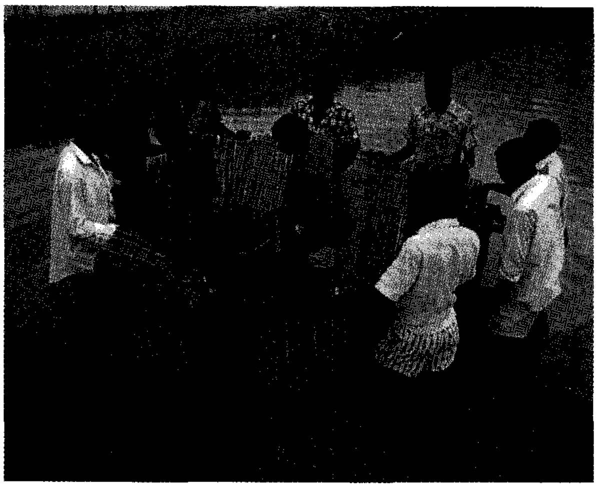


Fig. 4.5. Reed fence in action.

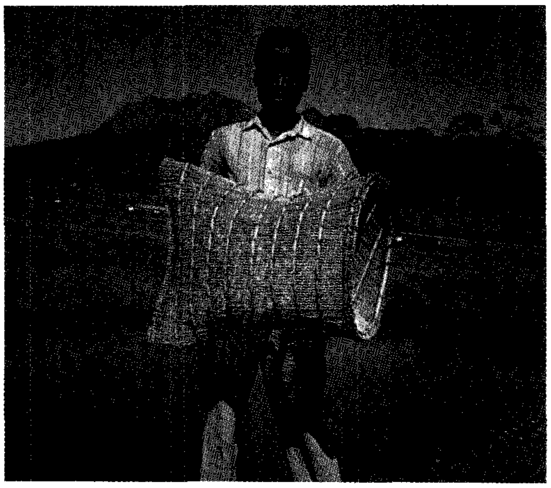


Fig. 4.6. Basket trap.

partial harvest systems. Three ponds each of four treatments (hook and line, traps, fence, unfished control) were stocked with 300 *O. shiranus* fingerlings (average weight 12.6 g). Pond inputs were locally available agriculture by-products (e.g., maize bran, maize stover compost and chopped weeds) in quantities based on those used by local farmers. Over 8 months, inputs averaged of 44.5 $kg\cdot ha^{-1}$ dry matter per day. After 4.5 months of growth, partial harvesting began. Weekly partial harvesting continued for an additional 4.5 months after which all ponds were harvested.

Results are tabulated in Table 4.7. Partially harvesting did not affect overall yield, but spread out the harvest over a longer period. Ponds fished with hook and line one afternoon per week yielded 968.5 $kg\cdot ha^{-1}$ over 264 days. Ponds fished with two basket traps produced 662.5 $kg\cdot ha^{-1}$ and ponds "seined" twice on one day per week with the reed fence produced 718.0 $kg\cdot ha^{-1}$. Unfished ponds produced 785 $kg\cdot ha^{-1}$. The fish taken by hook and line averaged 18.4 g, those taken in the traps averaged 6.3 g and those captured by the reed fence averaged 32.6 g. The fact that partial harvesting does not decrease yield is encouraging in social systems, such as that in Southern Malaŵi, where fish are regularly removed for special occasions in between normal harvests.

The weight frequency of fish taken by hook and line, the most effective partial harvesting method, is shown in Fig. 4.7. While there is no way to be sure of how fish will be

Table 4.7. Results of a partial study conducted at the Malaŵi NAC over 264 days. Hook and line and traps were used for four hours one afternoon per week. The reed fence was pulled twice through each pond during one day per week. All values are per 200 $m^2$ pond and represent the average of three replicates. Values within columns with different associated letters are significantly different ($P<0.05$).

| | At final harvest | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Adults | | Juveniles | | Fry | | Total | Partially harvested weight (kg) | Total harvested weight (kg) |
| Treatment | Number | Weight (kg) | Number | Weight (kg) | Number | Weight (kg) | Weight (kg) | | |
| Hook and line | 110a | 3.9 | 542a | 4.0 | 919a | 1.4 | 9.3 | 9.97a | 19.37a |
| Trap | 244b | 8.1 | 411a | 2.6 | 279b | 0.4 | 11.1 | 2.11b | 13.25a |
| Reed fence | 95a | 3.0 | 532a | 3.1 | 391b | 0.6 | 6.7 | 7.71a | 14.36a |
| Control | 300b | 10.7 | 432a | 2.8 | 1,079a | 2.2 | 15.7 | 0 | 15.70a |

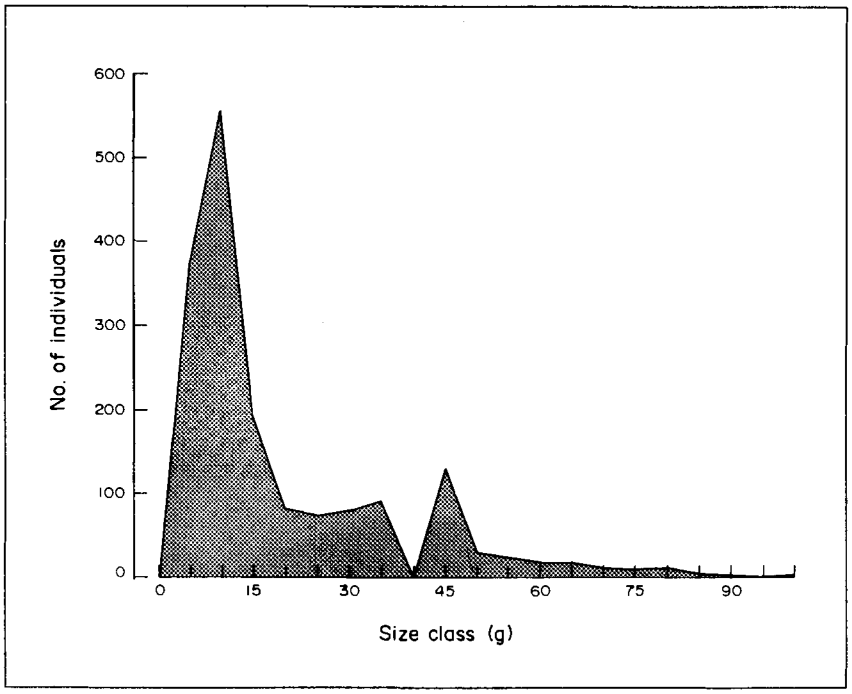


Fig. 4.7. Weight frequency of fish partially harvested by hook and line from 200 $m^2$ research ponds.

used in the rural household, the smaller weekly quantities of fish might be more likely to be eaten than the larger quantities of fish harvested at the end of the production cycle. The hook and line removal method is very usable by children.

*Fish Poisons*

An alternative to netting or trapping is the use of piscicidal plants to facilitate fish harvest. Fifty potential indigenous candidates were investigated by Chiotha et al. (1991). Of these, 14 (*Agave sisalana, Aloe swynnertonii, Bridelia micrantha, Breonadia microcephala, Ensete livingstonianum, Erythrophleum suaveolens, Euphorbia* (unidentified species), *Neorautenenia mitis, Opuntia vulgaris, Phytolacca dodecandra, Sesbania macrantha, Swartzia madagascariensis, Tephrosia vogelii, Xeromphis obovata*) were found to kill 95-100% of *Tilapia rendalli* and *Oreochromis shiranus* within 24 hours at a concentration of 100 $mg{\cdot}l^{-1}$.The potential risks to humans of eating fish killed in this manner have yet to be determined.

## Integrated Farming Technologies

Aquaculture technologies which consider the prevailing conditions on the target farm are more likely to be sustainably adopted than are those which are independent of the existing farming system (Chikafumbwa 1994a). In addition, the impact of aquaculture, once it is integrated into the farming system, goes beyond the pond dikes. In many cases, integrated aquaculture improves farm efficiency and profitability by increasing the productivity of vegetable gardens (Prein 1994) or maize fields (Brummett and Chikafumbwa 1995).

To demonstrate to farmers the pond input regimes described above, ICLARM-BMZ/GTZ, in collaboration with the Malaŵi Fisheries Department and the Malaŵi-German Fisheries and Aquaculture Development Project (MAGFAD), constructed a set of six "traditional" ponds integrated with vegetable plots, maize gardens, banana groves, *Leucaena* spp. hedgerows and ricefields (Fig. 4.8). The small ponds (50 $m^2$) are undrainable and filled with runoff and underground infiltration. Waste materials from the other enterprises are used as pond inputs. Fish are periodically partially harvested with a reed fence, traps or hook and line. No special efforts are made to control predation from birds and otters. Pond muds and water are used to fertilize the vegetable plots.

Fig. 4.8. Traditional ponds/gardens at the Malaŵi NAC.

In studies using these traditional ponds, Chikafumbwa (unpubl. data) obtained Chinese mustard cabbage, hybrid maize and *O. shiranus* standing crops of 43 $t \cdot ha^{-1}$, 42,000 $cobs \cdot ha^{-1}$ and 453.6 $kg \cdot ha^{-1}$, respectively (Table 4.8). The total productive area was 639 $m^2$ (250 $m^2$ of ponds and 139 $m^2$ of vegetable/maize garden). The entire system returned a net profit of $80.37 ($1,257.75 per hectare).

Integrated rice-fish farming offers new productive opportunities for farmers with land which is seasonally waterlogged. Table 4.9 shows the results of rice-fish trials conducted by Chikafumbwa (unpubl. data) in the traditional pond area from June 1990 through December 1993. Average net yield per average crop cycle (135 days) was 2.0 $t \cdot ha^{-1}$ of rice and 240.5 $kg \cdot ha^{-1}$ of fish.

A pilot study investigated the incorporation of nitrogen-fixing trees into crop-fish systems. The introduction of *Leucaena* trees (*Leucaena leucocephala*) increased total nitrogen harvested by 22.5% to 1.4 $t \cdot ha^{-1}$ on an annual basis. The maize subsystem contributed 73%, mustard

Table 4.8. Results of integrated maize-vegetable-fish trials used in the traditional ponds for the ICLARM-BMZ/GTZ Project. Vegetables and maize were intercropped on 139.2 $m^2$ and fish were grown in 250 $m^2$ of ponds.

| Crop | Period (days) | Inputs | Production (per hectare) | Total costs | Total income |
|---|---|---|---|---|---|
| Chinese cabbage | 60 | pond mud | 4.3 t | | |
| Hybrid maize | 78 | pond mud | 42,000 cobs | | |
| *Oreochromis shiranus* | 206 | *madeya* | 453.6 kg | US$53.90 | |

Table 4.9. Results of rice-fish integration trials conducted at the Malaŵi NAC in January 1990 - December 1993. *Faya* and *changu* are local rice varieties, T11 a hybrid. Fish were stocked at a rate of 2 per $m^2$. Rice was not fertilized and fish were not fed, unless otherwise indicated.

| Crop | Period (days) | Production ($kg{\cdot}ha^{-1}$) | Total costs | Total revenue | Comments |
|---|---|---|---|---|---|
| Rice (*faya*) | 176 | 1,040 | | | |
| *O. shiranus* | 176 | 280 | | | |
| Rice (*faya*) | 136 | 2,400 | | | |
| *O. shiranus* | 136 | 136 | | | |
| Rice (*faya*) | 129 | 3,500 | | | |
| Polyculture[a] | 133 | 122 | | | 70% of fish lost to flooding |
| Rice (T11) | 169 | 6,740 | | | fertilized[b] |
| *O. shiranus* | 186 | 309 | | | |
| Rice (*changu*) | 100 | 2,000 | | | heavy bird predation on rice |
| *O. shiranus* | 100 | 603 | | | supplemental feeding[c] |

[a] 1:1 polyculture of *Oreochromis shiranus* and *Tilapia rendalli.*

[b] 50 kg of diammonium phosphate + 45 kg of urea per hectare basal and 65 kg of urea per hectare of top dressing.

[c] 3% body weight per day of rice bran.

cabbage, 0.5% and fish, 4%. *Leucaena* leaves were not placed directly into the fishponds, but fell in accidentally and contributed significantly to dry matter in the pond sediments. Fish yield was 900 $kg{\cdot}ha^{-1}$ on an annual basis with an input regime of weeds and waste vegetables. An estimate 0.3% of the *Leucaena* leaves which fell into the ponds were harvested as fish.

The success of the integration research and demonstrations is evidenced by the adoption and self-dissemination of the technologies. For example, the rice-fish technology was completely new to southern Malaŵi when it was demonstrated to 35 farmers in 1990-1991. Seventeen of these farmers adopted rice-fish farming within a year. Within two years, 57 farmers were using the technology. By the end of 1993, rice-fish integration was practiced on almost 200 farms. This farmer-to-farmer diffusion of information occurred without the assistance of any organized extension effort.

## Rainfed Pond Systems

To increase the potential impact and widen the target group for integrated aquaculture, Brummett and Chikafumbwa (1995) conducted trials of the technical and economic feasibility of fishfarming systems based on ponds which hold water only during the rainy season (December through April). Results of a pilot study conducted in 1993-1994 are shown in Table 4.10.

Several positive impacts of the rainfed pond system were predicted. The construction of the pond in a part of the maize garden which was normally waterlogged during the rainy season should make more productive a part of the field which returned poor maize crops. Increasing the soil drainage in the immediate vicinity of the pond should permit the production of vegetables on the dikes or bananas on the wetter perimeter. The presence of a pool of water, which is occasionally replenished by rainfall, permits the more consistent watering of seedlings without the necessity of carrying water long distances from a community source.

Table 4.10. Stocking and harvest data for an evaluation of rainfed aquaculture in Zomba District, Malawi. Values for NAC represent the average of three replicates. Mr. Mtepa harvested his fish without informing the research team and without recording the data.

| Farmer | Pond area ($m^2$) | Fish species | No. | Average (g) | Total weight (kg) | Survival (%) | Average (g) | Standing stock (kg) |
|---|---|---|---|---|---|---|---|---|
| Ng'ombe | 80 | *T. rendalli* | 80 | 12.5 | 1.0 | 65 | 23.0 | 1.2 |
| | | *O. shiranus* | 120 | 36.6 | 4.4 | 80 | 50.5 | 4.9 |
| Kasichi | 100 | *T. rendalli* | 100 | 17.0 | 1.7 | 26 | 31.0 | 0.8 |
| | | *O. shiranus* | 150 | 36.0 | 5.4 | 80 | 44.5 | 5.4 |
| Mtikitira | 36 | *T. rendalli* | 37 | 17.6 | 0.7 | 0 | - | - |
| | | *O. shiranus* | 54 | 38.9 | 2.1 | 40 | 63.0 | 2.2[a] |
| Mtepa | 60 | *T. rendalli* | 60 | 14.2 | 0.9 | - | - | - |
| | | *O. shiranus* | 90 | 36.1 | 3.3 | - | - | - |
| NAC | 200 | *T. rendalli* | 200 | 10.5 | 2.1 | 99 | 26.3 | 5.2 |
| | | *O. shiranus* | 300 | 34.6 | 10.4 | 97 | 55.1 | 16.0 |

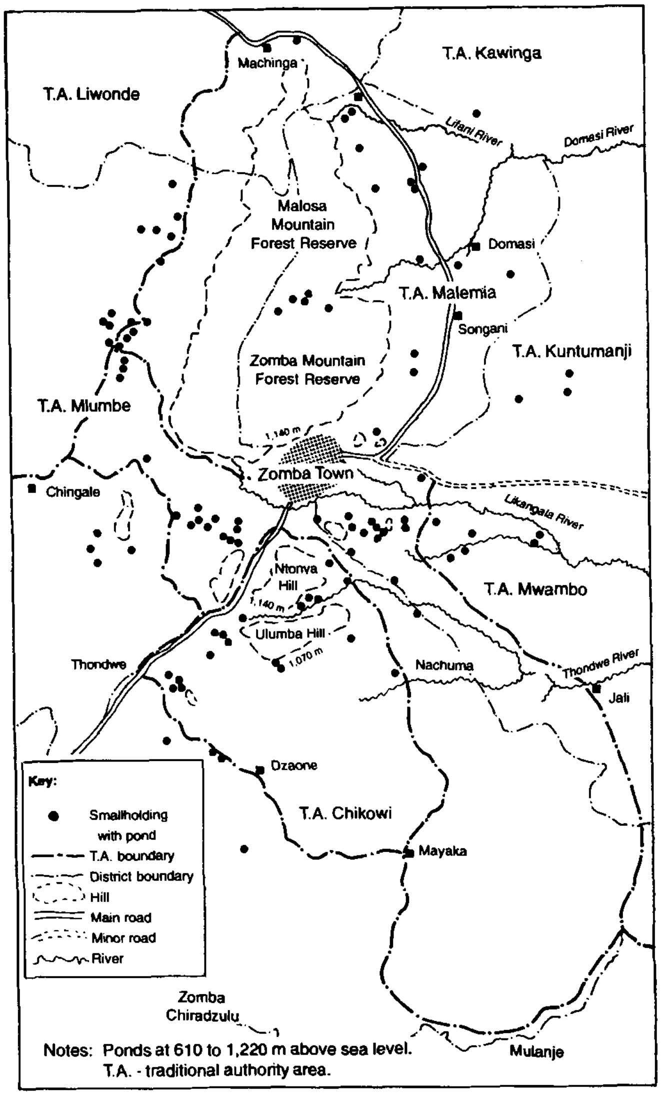
[a] Includes 414 fingerlings weighing 0.7 kg. No other pond had reproduction.

While many of these impacts will only be realized over the longer term, farmers in the test group were satisfied with their results despite the drought-induced shortness of the growing season. Average net profit of the system was $743 per hectare of pond surface. One farmer noticed an improvement in the maize harvest in the area near the pond. On her own initiative, one farmer moved a banana grove into the vicinity of the pond because "it seems that the left-over water and manure should help them grow". All test farmers deepened and expanded their ponds in preparation for the next rains. Even before the end of the experiment, two neighboring farmers constructed ponds and purchased fingerlings from project participants in response to the generally perceived success of the venture.

# CHAPTER 5

## Farming Systems Research

Research and development of appropriate aquaculture technologies for rural Africa were initially pursued along traditional lines in concentrating studies on-station at NAC. Farm surveys in 1989-1990 (Noble and Chimatiro 1991a, b) provided information on aquaculture activity (Fig. 5.1) and the type of resources available for aquaculture on small farms (Fig. 5.2; Noble, in press) This information helped researchers direct their on-station experiments towards what they perceived were the major biotechnical constraints to development of small-scale aquaculture. The culmination of this research approach and its results were presented at the 1990 ICLARM-GTZ conference in Malaŵi and in proceedings edited by Costa-Pierce et al. (1991).



Notes: Ponds at 610 to 1,220 m above sea level.
T.A. - traditional authority area.

Fig. 5.1. Partial distribution of small-scale farms with fishponds in Zomba District in 1988 (Noble, unpubl. data).

From the conference discussions, it became clear that on-station biotechnical research alone would not provide the answer to successful development of rural aquaculture. Research at NAC could never hope to adequately simulate and successfully incorporate the wide range of ecological, economic and social variables which influence rural aquaculture. Studies needed to be centered more on-farm in order to increase farmer involvement in designing aquaculture systems. On-station experiments needed also the "critical eye" of farmers to ensure relevance to farm conditions.

There was a growing realization that on small African farms, aquaculture could rarely be operated as a "stand-alone", single-commodity enterprise. Most farmers are resource-poor and cannot afford to purchase formulated feeds and fertilizers demanded by commercial aquaculture. Often, farms are managed to maximize food security rather than cash income (Noble and Costa-Pierce 1992). This is not to deny that aquaculture has

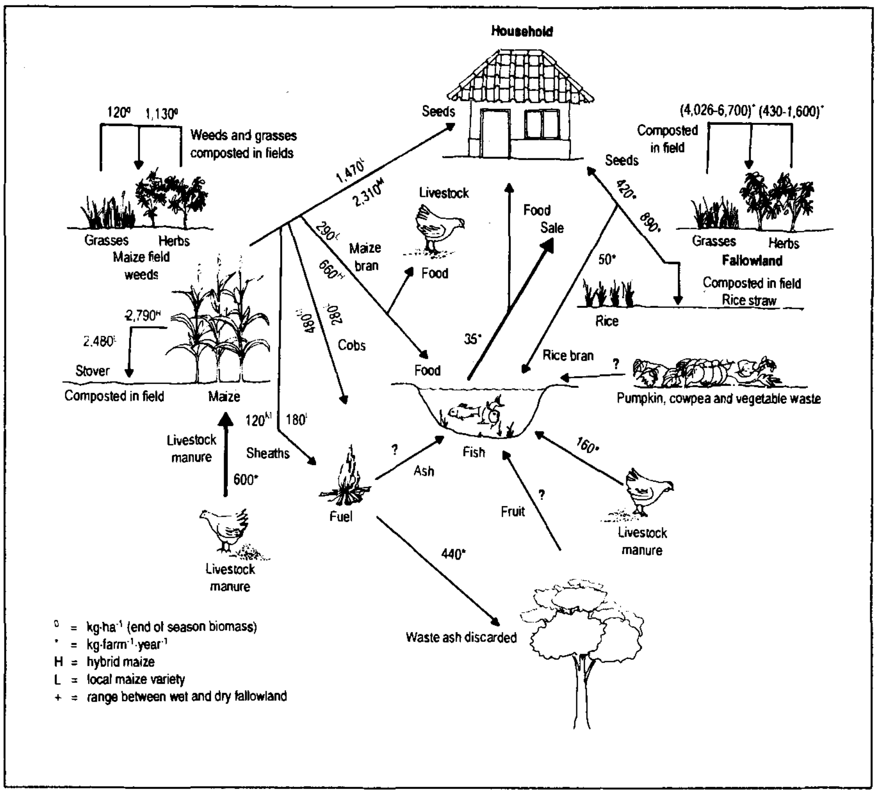


Fig. 5.2. Composite bioresource flow diagram for a Malaŵian smallholder farm practicing aquaculture (Noble, in press).

potential for increasing household income. However, it will probably only effectively do so if integrated into current agricultural practices with minimal demands on farm resources. So from early 1990, the ICLARM project began to evolve a Farming Systems Research (FSR) perspective with on-station experiments acting as backup. The first step in this process was to encourage farmers to visit NAC to review the research program.

## Technology Transfer

Traditionally, researchers develop aquaculture technologies on-station based on what they think are the most common problems farmers will face. Often, little chance is given to farmers during the early stages of research to provide their input and ensure the relevance of aquaculture technology being developed.

Up until 1990, the ICLARM project in Malaŵi had concentrated its research efforts at NAC albeit based on detailed information concerning local farming systems. A suite of potential technologies had been developed but before extension personnel took them out to farmers, it was essential for the clients (i.e., the farmers) to review the relevance of the aquaculture management options on offer.

Farmer open days at NAC began in May 1990 and were carefully structured to ensure that farmers could freely express their opinions about the research program. Technologies were reviewed in the morning and then farmers led afternoon workshops to review all they had seen. Farmers were very enthusiastic about having an input into research and did not spare their criticisms where needed (Noble and Kadongola 1990; Noble and Rashidi 1990). Such an open-day format stimulated both researchers and farmers and inevitably led to farmers, of their own volition, taking up some of the technologies.

A rapid survey was conducted in late 1990 to assess this adoption of aquaculture management options. Table 5.1 from Noble and Rashidi (1990) demonstrates the range of technologies under test by farmers after visiting NAC. Apart from the open days, there had been no further exposure of farmers to aquaculture systems. From this initial survey, not only farmers who had visited NAC tried out technologies but also some who had never visited the station. So significant farmer-farmer transfer of ideas had occurred. However, major adoption was restricted to farmers who had attended open days: 76% of these farmers tried out more than one aquaculture innovation compared to 32% of those who had not attended an open day.

Table 5.1. Comparison between two groups of farmers as to their uptake of aquaculture technologies for testing on-farm (Noble and Rashidi 1990).

| Type of aquaculture technology | No. of farmers testing a particular technology<br>OP[a] (N=29) | <br>Non-OP[b] (N=25) |
|---|---|---|
| Napier grass inputs | 20 | 3 |
| Poultry manure inputs | 17 | 16 |
| Vegetable-fish integration | 13 | 11 |
| Rice-fish integration | 7 | 1 |
| Terrestrial compost input | 6 | 0 |
| Pond stirring | 5 | 0 |
| Reed fence for harvesting | 7 | 1 |
| Smoking kiln | 1 | 0 |

[a] OP - present at open days.
[b] Non-OP - not present at open days.

Four conclusions were apparent: (1) open days were useful in encouraging farmers to consider adopting technologies; (2) many of the technologies being tested at NAC were applicable to local farming environments with minor modification by farmers; (3) exposure of a few farmers to potential aquaculture innovations could encourage a broader group to test out technologies via farmer-farmer transfer of ideas; and (4) researchers found farmer input was essential for designing sensible aquaculture technologies.

## Rice-fish Integration

Rice-fish integration provides an excellent example of the efficacy of open days at NAC. In December 1990, farmers were shown an experimental rice-fish pond, a complete novelty for them. At the afternoon workshop, farmers were excited by its potential but critical of the NAC design. Basically, farmers felt that the station pond was too clumsily arranged for harvesting fish easily. They went on to draw pictures of how they would integrate fish and rice (Fig. 5.3). All of their designs demonstrated easier, more efficient arrangements for harvesting fish and rice than those of the researchers. Seventeen farmers attended this first open day on rice-fish integration. By February 1991, eight were experimenting with rice-fish culture and eventually achieved annual pond production levels of 2.4-4.0 $t \cdot ha^{-1}$ for rice and 1.5-2.4 $t \cdot ha^{-1}$ for fish (Noble and Costa-Pierce 1992).

Encouraging returns in cash and food to farmers combining rice and fish convinced many of their neighbors to try out the system. By the end of 1991, over 40 farmers who had not attended NAC open-days were experimenting with rice-fish culture. Fourteen rice-fish ponds with mean pond area 259 $m^2$ and rice area 124 $m^2$, gave average annual yields of 0.55 $kg \cdot m^{-2}$ of rice (S.D. 0.20; range 0.35-0.96) and 0.13 $kg \cdot m^{-2}$ of fish (S.D. 0.06; range 0.12-0.22). For the average-sized rice-fish pond, the cash value of these crops was $16 and $35, respectively. Considering that annual rural-family incomes were approximately $150-$200 in 1991, rice-fish systems were making a significant contribution to household economy (Lightfoot and Noble 1993).

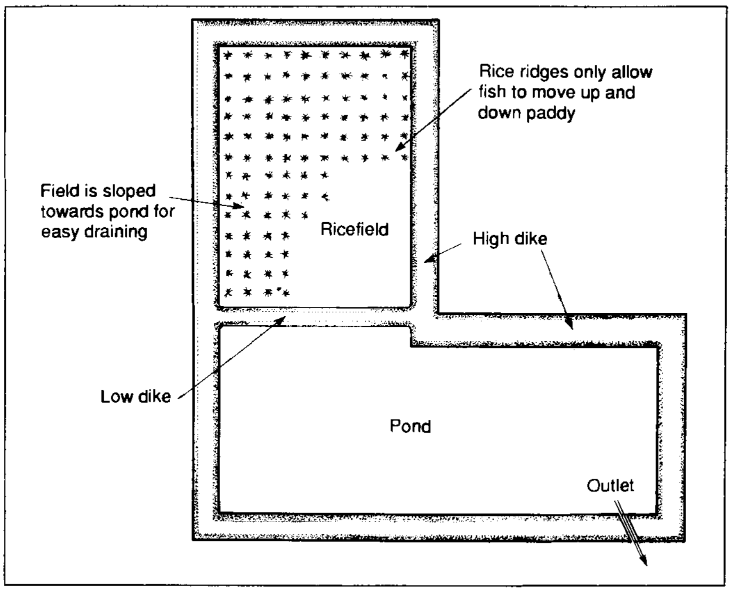


Fig. 5.3. Malaŵian farmer's drawing of a possible rice-fish arrangement (two farmers composed the drawing).

The success of rice-fish integration was the result of several factors: (1) accurate targeting of farmers (i.e., those who already grew rice and had ponds); (2) providing a new system which would not involve major changes in farming practice and was perceived to be low-risk by farmers; (3) rice-fish integration could be modified to suit a variety of local conditions; and (4) rice-fish is a low-cost innovation in terms of cash.

Most of the rice-fish systems conformed to one particular design as shown by Figs. 5.4 and 5.5. However, farmers did experiment with many different arrangements, some planting rice as a border to their ponds (Fig. 5.6) and some planting almost their entire pond with rice except for a small fish refuge near the outlet (Fig. 5.7). Within a year, farmers produced rice-fish pond systems where the two crops could be easily de-coupled to facilitate harvesting when needed. All of this

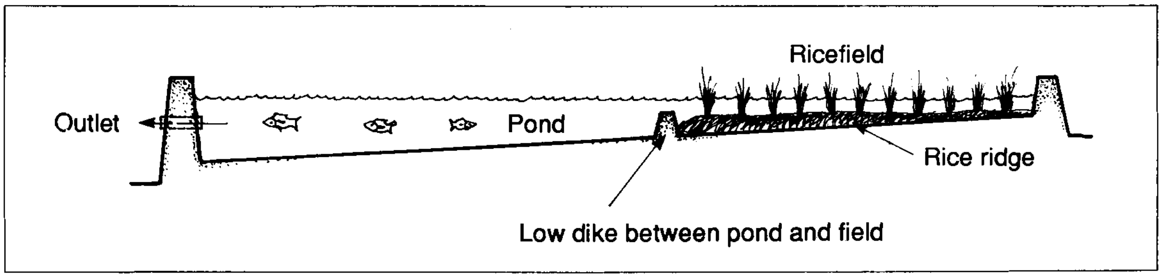


Fig. 5.4. A sloping ricefield makes it easier to drive fish into the pond; afterwards rice can be harvested.

Fig. 5.5. First rice-fish pond in Malaŵi: Anusa-Issa family.

Fig. 5.6. Rice bordering farmers' pond: Singano family.

Fig. 5.7. Rice-fish pond with small fish refuge: Maundala-Salimu family.

development occurred without further input from researchers. It demonstrated clearly that farmers took up ideas readily and could modify them very effectively to suit their own circumstances. All the farmers needed was the stimulation provided by the open days.

Open days for farmers continued in collaboration with the Malaŵi Department of Fisheries and the MAGFAD extension project, with ICLARM playing a supporting, but not a major role after 1990. The initial open days had aptly illustrated the importance of farmer input on-station and it was now for the extension service to take advantage of them. The next development in the farmer participatory and FSR program was on-farm studies of biotechnical constraints to producing fish.

## On-farm Biotechnical Pond Experiments

In early 1992, the first on-farm pond experiments took place in Chinseu, Zomba District. Five fishfarming clubs were approached to participate in testing a new fish species for aquaculture (*Oreochromis saka* (*karongae*)) from Lake Malaŵi in combination with *Tilapia rendalli*. Clubs were chosen because there were too few *O. saka* to distribute to individual farmers and to avoid the problem of only favoring a few farmers with the new species. Operating an experiment with clubs provided, at best, an approximation to conditions on individual farms.

Farmers decided on the experimental regimes such as pond size, type and level of pond inputs, duration of experiment, etc. Researchers monitored water quality, input rates and fish growth on a regular basis so that farmers had a constant update on the effects of their management regime. Some details of experimental results are presented in Fig. 3.6 and Table 3.5 (Noble, unpubl. data).

The innovation in this whole process was the holding of a workshop for the fish clubs in July 1992 at a Fisheries Department extension station. Researchers provided farmers with experimental results in a pictorial form to enable illiterate farmers to understand them. (Figs. 5.8 and 5.9). Farmers led the discussion on the experiment and quickly understood how pond inputs affected water quality and fish growth even though over 50% of them were functionally illiterate.

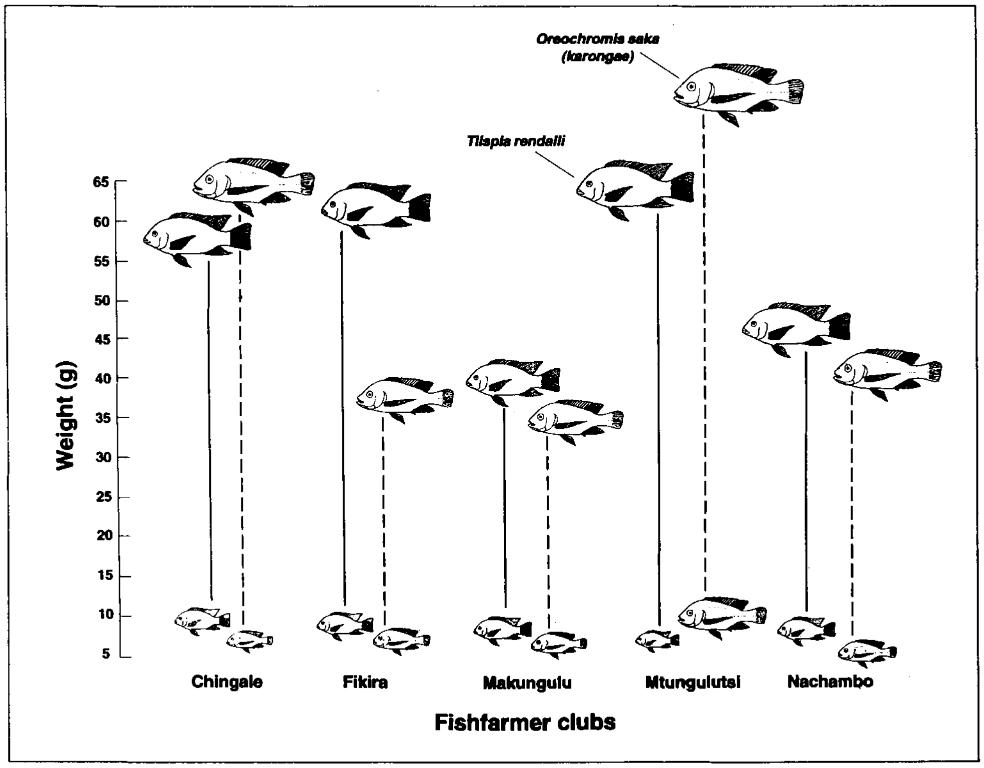


Fig. 5.8. Diagram of results from *O. saka/T. rendalli* on-farm experiment.

Fig. 5.9. Farmers at workshop on *O. saka/T. rendalli* on-farm experiment.

As shown in Fig. 5.9, a simple histogram was drawn of conductivity and pond inputs and this was placed beneath the diagrams for fish growth. Conductivity was chosen as a parameter which provided the easiest indication of water fertility and was fully explained to the farmers. Pond inputs were represented by one bar which was divided proportionally into brown and green to represent levels of maize bran and green leaf inputs, respectively. Images of the fish were photocopied to life-size and combined with histograms of growth to illustrate the differences in average fish size between stocking and harvesting.

Farmers conducted a workshop evaluation of the experiment and agreed that it had been an innovative and exciting way to understand fishpond management. It was the first attempt by the project to encourage farmers to run experiments and participate in their design and evaluation. The study may not have been as fully participatory as one would have liked but, it did act as useful precursor to the farmer-led study conducted in 1993 on *O. shiranus* and *T. rendalli* reported below and by Brummett and Noble (1995).

In this experiment, farmers decided the objectives and experimental regime. Researchers provided fingerlings of uniform size and backup in terms of monitoring water quality, input levels and help with fish sampling. Combined with the on-farm experiment were simulation experiments at NAC to more rigorously examine the effects of input regimes farmers were using (Brummett and Noble 1995). At the end of the experiment, individual farmers received their results, those of other farmers and from on-station. There was unfortunately no chance to have a workshop on the experiment. However, farmers were able to see that depending on type and level of input, fish grew at different rates. They also realized from what each other was doing, that a wide range of potential farm inputs could be used in ponds.

These two participatory research experiments demonstrated that farmers: (1) are eager to take active part in experiments, particularly if they play a major role in setting the protocols; (2) are well capable of analyzing and understanding the implication of research results; and (3) do make management changes based on research findings. In turn, researchers realized that: (1) farmers should set the agenda for on-farm experiments; (2) farmers should self-select for taking part in the experiment, rather than researchers selecting farmers; and (3) farmers should be allowed free access to results, which should be in a form that illiterate farmers can understand.

As a result of both experiments, the farmers involved are now using a much wider range of bioresidues in their ponds and monitoring water fertility much more closely. There is also a growing realization that fish are a crop like any other and require careful management to ensure reasonable production levels. This latter point is an important change because many farmers paid scant attention to pond input regimes before taking part in the experiments.

## Integrated Aquaculture-Agriculture and Resource Management

A major aim of development research, whether in aquaculture, trees, livestock or crops, should be to create sustained improvements in living standards for resource-poor farmers. Lightfoot and Noble (1993) commented that most development research is commodity-oriented and does not address the needs of farmers managing their land for maximizing food security rather than cash income. In Malaŵi, over 80% of farmers are resource-poor.

Hence, biotechnical research should concentrate on problems of practicing aquaculture in resource-limited environments. This requires that researchers take a broader perspective of the role fishponds could play on small farms rather than dwell on aquaculture systems reliant on costly external inputs.

Utilizing fishponds as multipurpose units which help to rehabilitate marginal land and make more efficient use of farm bioresidues may make aquaculture a more inviting proposition for small farmers. To achieve this objective requires a new set of protocols for enabling farmers to appreciate ponds as systems for environmental improvement.

Development of a suitable participatory methodology started with the resource surveys carried out in 1989 and 1990 (Noble and Chimatiro 1991a; Noble, in press) which established resource availability for aquaculture. In 1990, open days followed at NAC whereby farmers saw the potential for integrating ponds with other farm enterprises by recycling bioresidues between them. At these open days, farmers were encouraged to draw possible scenarios for integrating fishponds into other activities on their farms (e.g., farmer design of rice-fish systems). Coupled with the open days, researchers went out onto farms to encourage farmers to make pictorial representations of their resources and current level of integration between enterprises.

Now, a procedure has been established which takes farmers through a series of steps until they are designing their own integrated crop-pond systems. Initially, a farmer group is brought together to construct village resource maps and transects (Figs. 5.10 and 5.11). This establishes the resource base for the community. Then maps for individual farms are drawn. The community and farm maps make it easy to discuss possibilities for incorporating aquaculture onto farms. Farmers can use their diagrams to discuss among themselves how resources might be recycled between ponds and other enterprises. The advantage of this approach is that illiterate farmers can draw and easily understand pictures, hence, are not excluded from the design process (Lightfoot et al. 1991).

Farmers from Chinseu, Zomba District, have been exposed to this participatory process and have designed various crop-pond systems which have improved overall performance of their farms. Fig. 5.12 shows a drawing by a woman-farmer of how she integrates her ponds with other enterprises on her farm. Prior to having ponds, there was little or no recycling of farm residues. Now, she intensively recycles many materials on her farm and not just between her ponds and other enterprises.

An essential feature of the farmer-researcher interaction is to monitor and evaluate impact of integrating aquaculture into farming activities. Transects and maps can be used on a regular basis to measure seasonal changes in farm management coupled with evolutionary changes which occur when new enterprises such as aquaculture are adopted. This has been done for six farmers in Chinseu, Zomba District.

Monitoring was restricted to six farmers because of logistics. They were chosen to represent a range of locations from mountain slopes to flat, open farmland. All of the farmers were practicing aquaculture when monitoring began, but had been exposed to the process of mapping, transects, etc. They had also been to open days at NAC.

Monitoring began in 1990/91 for some of the farmers. Data for periods prior to adopting aquaculture were obtained through mapping and extended discussion on farm management. Table 5.2 shows the economic performance of these farms over several years. Farmers in mapping sessions identified four basic resource types on their farms:

*Munda* - seasonal cropland (crops grown from November to May)

*Dimba* - vegetable gardens with high water table (crops grown almost throughout the year)

Ponds - fishponds (fish grown throughout the year except in severe drought)

Home - homestead (includes seasonal garden around house, livestock, trees, etc.)

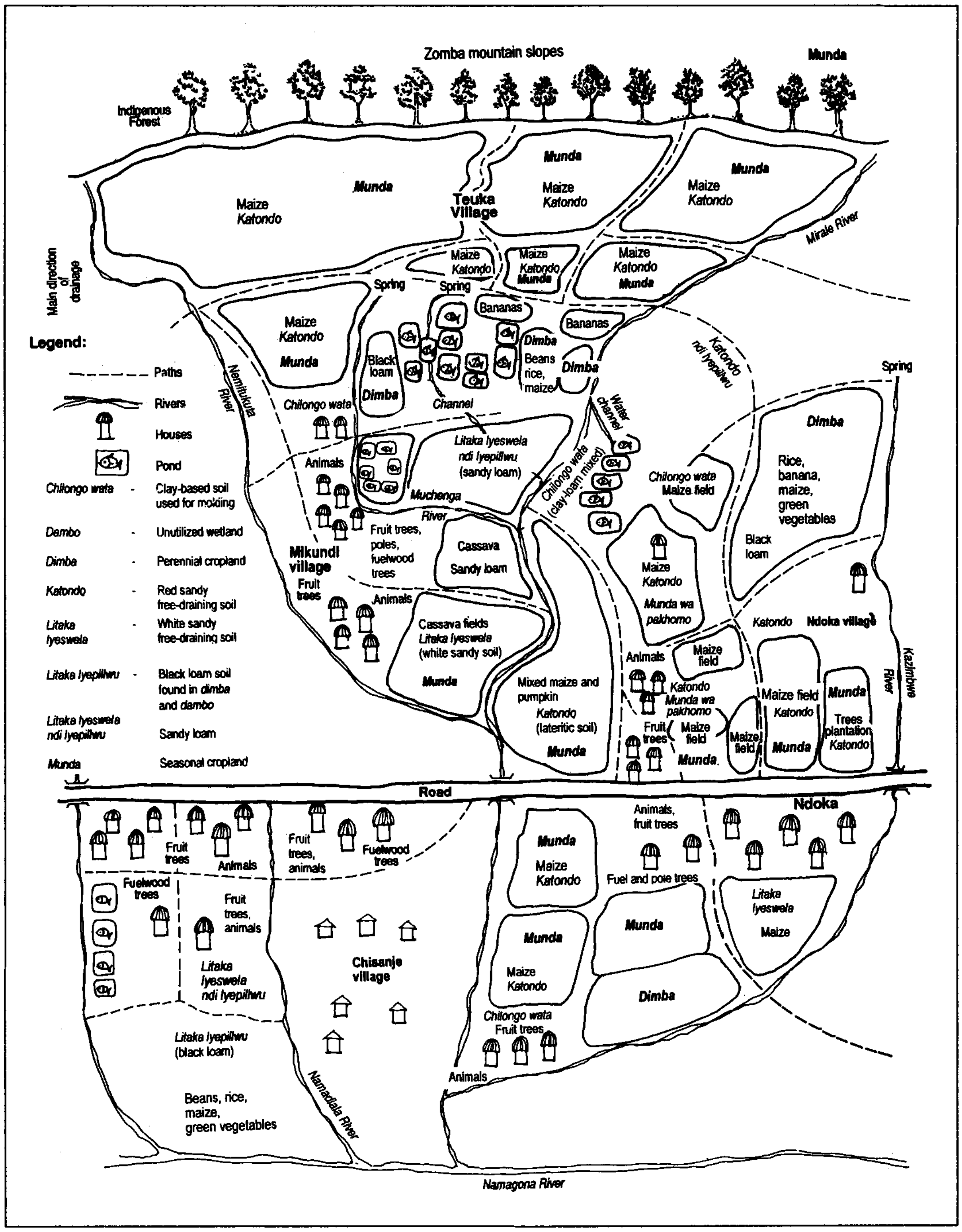
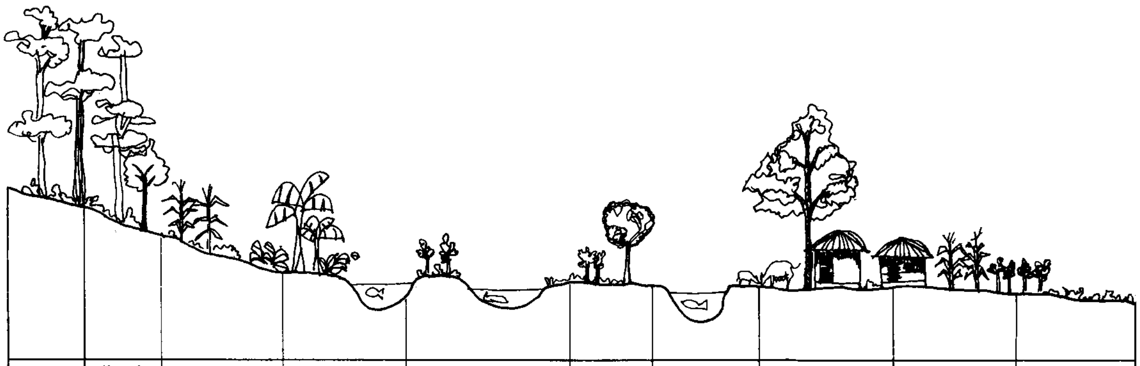


Fig. 5.10. Resource system map redrawn from original map made by villagers in Chinseu, Zomba District, Malaŵi.



| **Resource system** | **Mountain slope**<br>***Mtunda*** | **Perennial cropland**<br>***Munda*** | **Perennial cropland**<br>***Dimba*** | ***Dimba*** | ***Dimba*** | ***Dimba*** | **Seasonal cropland**<br>***Munda wa pakhomo*** | ***Munda*** | **Perennial cropland**<br>***Dimba*** |
|---|---|---|---|---|---|---|---|---|---|
| **Water resource** | Rain | Rain | Springs, rain | Springs, rain | Rain | Rain | Rain | Rain | Rain |
| **Soil** | Laterite<br>*Katondo ya kamusa* | Red sandy (iron-rich)<br>*Katondo ya kamusa* | Black *dambo*<br>*Litaka lyepilwu* | Sandy loam (grey)<br>*Litaka lyepilwu ndi lyeswela* | Sandy loam<br>*Chilongo wata* | Sandy loam (red brown)<br>*Katondo ndi lyepilwu* | Red sandy soil (iron-rich)<br>*Katondo* | Sandy soil<br>*Litaka lyeswela* | Sandy loam<br>*Litaka lysewela ndi lyepilwu* |
| **Crops** | Mushrooms | Maize, cassava, cucumber, sunflower, sorghum, potatoes, pigeon peas, finger millet, beans, pumpkin, peppers | Bananas, beans, sugarcane, cucumber, peppers, finger millet, Irish potatoes (dry season)<br>Peas, maize, rice, pumpkin, pigeon peas, finger millet, Irish potatoes, peppers | Maize, pumpkin, sugarcane, cucumber, bananas, beans, green vegetables, tomatoes (dry season)<br>Cassava, maize, bananas, sunflower, sorghum, peppers, finger millet, potatoes, cucumber, sugarcane | Cassava | Maize, pumpkin, sunflower, cucumbe beans, Irish potat sweet potatoes, finger millet, rice, cassava, peppers | Maize, pumpkin, beans, finger millet, sunflower, cucumber, pigeon peas, sweet potatoes | Green vegetables, beans, maize, tomatoes | Rice, cassava, sweet potatoes, maize, sugarcane, sunflower, rice |
| **Trees** | Natural woodland | | | | Eucalyptus<br>*gmelina, pawpaw,*<br>acacia | | Mango, pawpaw, avocado, guava, citrus | | |
| **Animals** | ← Goats, cattle, sheep, dry season grazing → | | Fish | Fish | | Fish | ← Goats, cattle, sheep →<br>Goats, chicken, cattle, rabbits, guinea pig, sheep, ducks | | |

Fig. 5.11. Land transect of village in Chinseu, Zomba District, Malaŵi, January 1990.

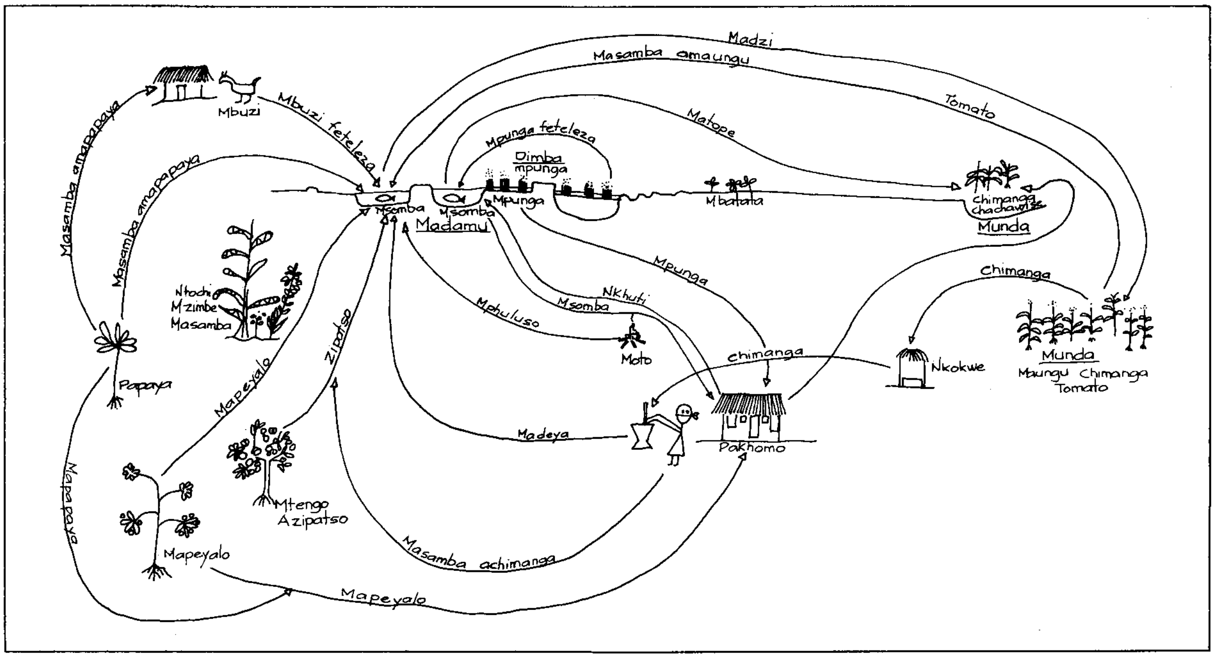


Fig. 5.12. Drawing of recycled resources on the Mwalanga farm, Ndoka village, Zomba District, Malaŵi.

Table 5.2. Cash and noncash income generation on six Malawian farms in Chinseu, Zomba District. All figures are in US$.

a. Annual net cash income for each resource type.

| Farmer | Resource type<br>*Munda* | *Dimba* | Ponds | Home | Total |
|---|---|---|---|---|---|
| Amadu | 87 | 61 | 36 | 28 | 212 |
| Austen | 93 | 104 | 68 | 12 | 277 |
| Dimo | -8 | 23 | 8 | 13 | 36 |
| Duwa | -15 | 31 | 28 | 24 | 68 |
| Gunda | -63 | 20 | 32 | -8 | -20 |
| Salimu | 48 | 78 | 84 | - | 210 |
| Mean | 24 | 53 | 43 | 14 | 131 |
| SD | 57 | 31 | 25 | 13 | 108 |

Percentage (%) contribution to net cash income:
*Munda* - 18 Ponds - 32
*Dimba* - 40 Home - 10

b. Annual net cash income/100 $m^2$ of each resource type.

| Farmer | Resource type<br>*Munda* | *Dimba* | Ponds | Home |
|---|---|---|---|---|
| Amadu | 1 | 2 | 6 | 3 |
| Austen | 3 | 34 | 5 | 6 |
| Dimo | -0.1 | 2 | 6 | 1 |
| Duwa | -0.1 | 2 | 2 | 1 |
| Gunda | -0.4 | 1 | 7 | 0.2 |
| Salimu | 0.1 | 3 | 8 | - |
| Mean | 1 | 7 | 6 | 2 |
| SD | 1 | 12 | 2 | 2 |

c. Annual total net income from each resource type.

| Farmer | Resource type<br>*Munda* | *Dimba* | Ponds | Home | Total |
|---|---|---|---|---|---|
| Amadu | 193 | 91 | 38 | 58 | 380 |
| Austen | 199 | 125 | 39 | 53 | 415 |
| Dimo | 39 | 36 | -12 | 29 | 93 |
| Duwa | 28 | 53 | 15 | 73 | 169 |
| Gunda | 107 | 43 | 41 | 37 | 227 |
| Salimu | 48 | 78 | 84 | - | 210 |
| Mean | 102 | 71 | 34 | 50 | 249 |
| SD | 71 | 31 | 29 | 23 | 114 |

Percentage (%) contribution to total net income:
*Munda* - 40 Ponds - 13
*Dimba* - 28 Home - 19

d. Annual total net income/100 $m^2$ of each resource type.

| Farmer | Resource type<br>*Munda* | *Dimba* | Ponds | Home |
|---|---|---|---|---|
| Amadu | 1 | 2 | 5 | 6 |
| Austen | 1 | 11 | 2 | 2 |
| Dimo | 0.3 | 3 | -0.4 | 3 |
| Duwa | 1 | 3 | 0.1 | 2 |
| Gunda | 1 | 2 | 9 | 3 |
| Salimu | 0.5 | 4 | 7 | - |
| Mean | 1 | 4 | 4 | 3 |
| SD | 0 | 3 | 4 | 1 |

*Munda* : seasonal cropland which is rainfed.
*Dimba* : cropland with high water table, often receiving spring water as well as rain.
Ponds : fishponds.
Home : homestead which includes livestock, woodlot, fruit trees and often a small seasonal rainfed garden.

Total net income = balance of cash inputs and outputs (e.g., opportunity costs for family labor, use of own seeds for planting, etc.) and noncash (e.g., produce eaten, given away, etc.)

The *dimba* and ponds generate more of the annual net income, $53 and $43, respectively, than do the *munda* and homestead, $24 and $14, respectively (Table 5.2a). The *dimba* contributes on average 40% towards annual cash income; ponds, 32%; *munda*, 18% and homestead, 10%. These results suggest that ponds do have a significant effect on family economy. Table 5.2b lists the values for individual farm and the means for each resource system over the six farms per unit area. The *dimba* and pond resource type areas are very valuable. Each generates between $6 and $7 per 100 $m^2$ per year compared with between $1 and $2 for the *munda* and homestead, respectively.

Total net income does not seem to provide such clear evidence of the efficacy of ponds. Net income includes both cash and noncash inputs which are balanced against cash and noncash outputs. The contribution of ponds to annual income falls to 13% (Table 5.2c) when noncash inputs and outputs are included. Farmers found it very difficult to estimate values of family labor which make up a large amount of the noncash input. Also estimating hours of family labor is notoriously difficult and prone to wide errors depending on whom one speaks to in the family. In comparison, farmers are often fairly accurate about cash inputs and outputs. Interestingly enough, when one looks at annual net income generation per 100 $m^2$ of resource type (Table 5.2d), again *dimba* and ponds prove to be more valuable per unit area than *munda* or homestead.

Tables 5.3a and 5.3b show returns on investment for different resource types. For cash generated per $1 invested by farmers, ponds are clearly the most productive system (Table 5.3a). The picture is reversed for annual net income where ponds are the lowest ($0.5 generated per $1 invested). Part of the reason for this reversal is the large amount of family labor used for pond construction. In many cases, the value of this labor has not been fully recouped. Also, farmers are continuing to build ponds and hence family labor is a significant noncash input. The homestead scores high both in returns on cash investment and total investment because money is being generated mostly from trees, fruit and occasional sales of goats or chickens. None of these crops or livestock require much in cash or noncash input once established on the farm.

Table 5.3. Returns on investment from each resource type for six small farms in Chinseu, Zomba District.

a. Amount of annual cash income in US$ generated per dollar invested.

| Farmer | Resource type<br>*Munda* | *Dimba* | Ponds | Home |
|---|---|---|---|---|
| Amadu | 1 | 1 | 17 | 29 |
| Austen | 2 | 32 | 39 | 0.4 |
| Dimo | 0.3 | 1 | 10 | 12 |
| Duwa | 0.1 | 2 | 13 | 0.7 |
| Gunda | 0.2 | 3 | 9 | 0.8 |
| Salimu | 0.4 | 2 | 1 | |
| Mean | 0.5 | 7 | 15 | 9 |
| SD | 0.5 | 11 | 12 | 11 |

b. Amount of annual total income in US$ generated per dollar invested.

| Farmer | Resource type<br>*Munda* | *Dimba* | Ponds | Home |
|---|---|---|---|---|
| Amadu | 1 | 1 | 1 | 6 |
| Austen | 1 | 2 | 1 | 1 |
| Dimo | 0.4 | 1 | 0.2 | 2 |
| Duwa | 0.3 | 0.7 | 0.4 | 1 |
| Gunda | 0.3 | 0.7 | 0.3 | 2 |
| Salimu | 0.6 | 0.7 | 0.3 | |
| Mean | 0.6 | 1 | 0.5 | 3 |
| SD | 0.3 | 0.4 | 0.3 | 2 |

Note: Total net income includes cash inputs and outputs (e.g., produce eaten, given away, etc.) and value of noncash inputs (e.g., opportunity costs of family labor, use of own seeds for planting, etc.)

Overall, the data from these joint farmer-researcher evaluations suggest that ponds are important and valuable enterprises for small African farms. Figs. 5.13a-d demonstrate the impact of ponds on the economy of one of the six farmers. Figs. 5.13a and 5.13b show the variation in annual net cash and total income over five years. *Dimba* and pond incomes have been combined because these systems are closely integrated. The *dimba*-pond system clearly makes a major contribution to farm income. This becomes more obvious in Figs. 5.13c and 5.13d where values per unit area of resource type are compared. For cash income, the *dimba*-pond integration is the most valuable resource system per unit area. The homestead becomes most valuable when total income is measured because of the small amount of family labor needed to tend the enterprises around the home.

The *dimba*-pond system of the Amadu family was built in a *dambo* (uncultivated, low-lying land prone to flooding in wet season), unused until 1988-1989 when the first ponds were built. Income generated from these ponds enabled the family to employ labor to clear the *dambo* and build an adjacent *dimba* (Fig. 5.14). This situation is not uncommon. Of the six farmers under study, three brought marginal unproductive land into production through building ponds. In all cases, the ponds have not only been used for producing fish but also for water management. The pond enables *dimba* gardens to be developed in areas which were either too dry before or had been prone to flooding.

Another farming family (Salimu) has converted the *dambo* next to their house into five ponds and built three small *dimba* gardens between the ponds (Fig. 5.15). Maize is also being grown in pond bottoms so that land is fully utilized when there is insufficient water to keep all ponds full. This family operates the following sequence in their vegetable-pond integration:

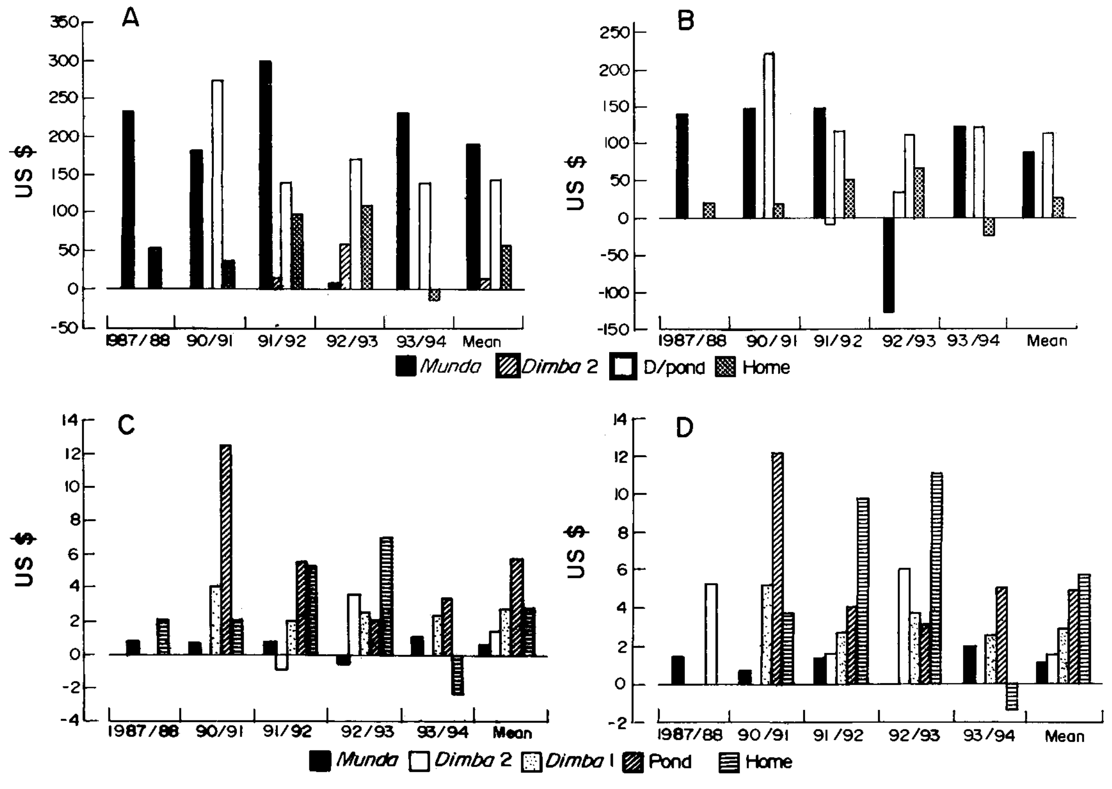


Fig. 5.13. Economic performance of resource types on a small African farm practicing crop-pond integration; (A) annual net cash income from each resource type; (B) total annual net income from each resource type; (C) annual net cash income generated per 100 m$^2$ of resource type; and (D) annual total net income generated per 100 m$^2$ of resource type.

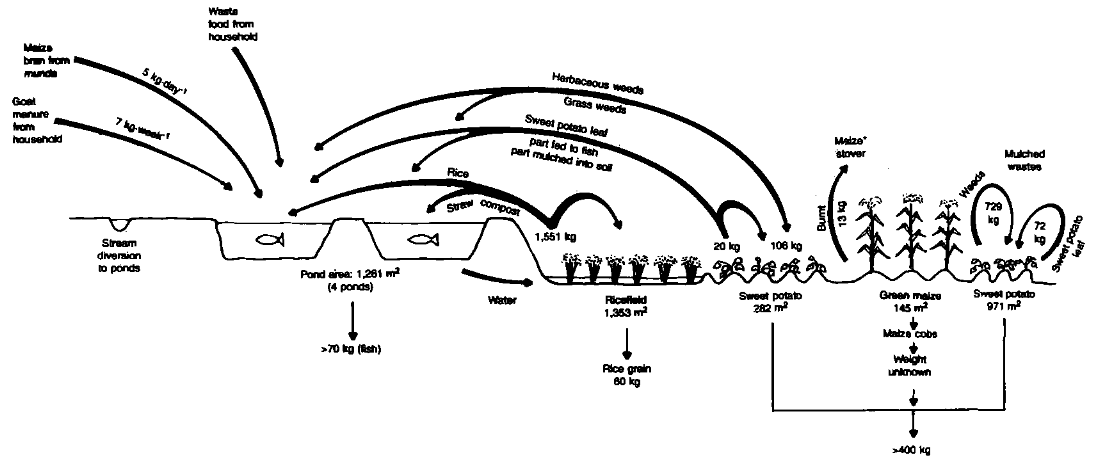


Fig. 5.14. Integrated *dimba*-pond system on the Amadu farm showing partial estimates of biomass production and the fate of bioresidues (Noble, unpubl. data).

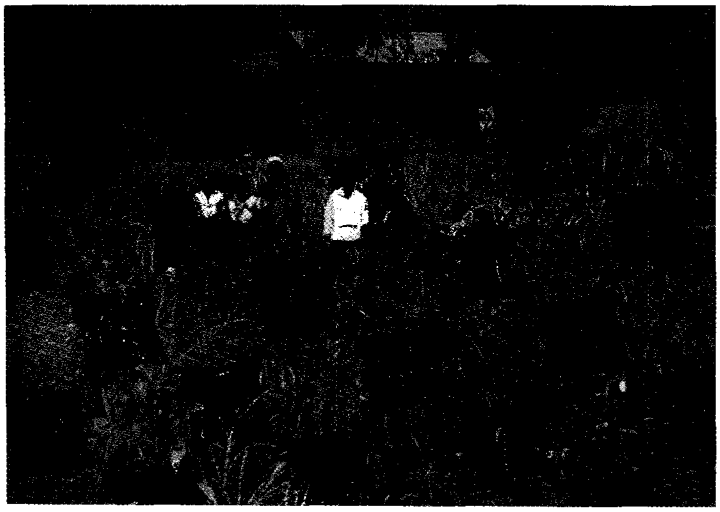


Fig. 5.15. Growing crops in dry pond bottoms.

November-June - rice-fish in three ponds/two ponds for fish production only; vegetables (onion, tomato, green maize) on pond dikes

July-October - maize intercropped with pumpkin and beans on bottoms of three ponds (Fig. 5.15); two production ponds for fish

The ponds average 250 $m^2$ and the vegetable gardens are 14 $m^2$, 15 $m^2$ and 70 $m^2$, respectively. The whole system generated $84 in cash from November 1993 until October 1994. In a Malaŵian context, this is a large contribution to income.

One effect of introducing ponds on farms has been a marked increase in recycling of bioresidues as demonstrated in Fig. 5.16. The number of bioresidues being recycled increased on average from two to eight over the six farms. This includes recycling between all enterprises. Such recycling makes better use of farm resources and cuts costs of farm operation. For instance, most of the farmers do not pay for pond inputs; they use their own crop and livestock wastes. Likewise, ponds contribute water and fertile mud to adjacent

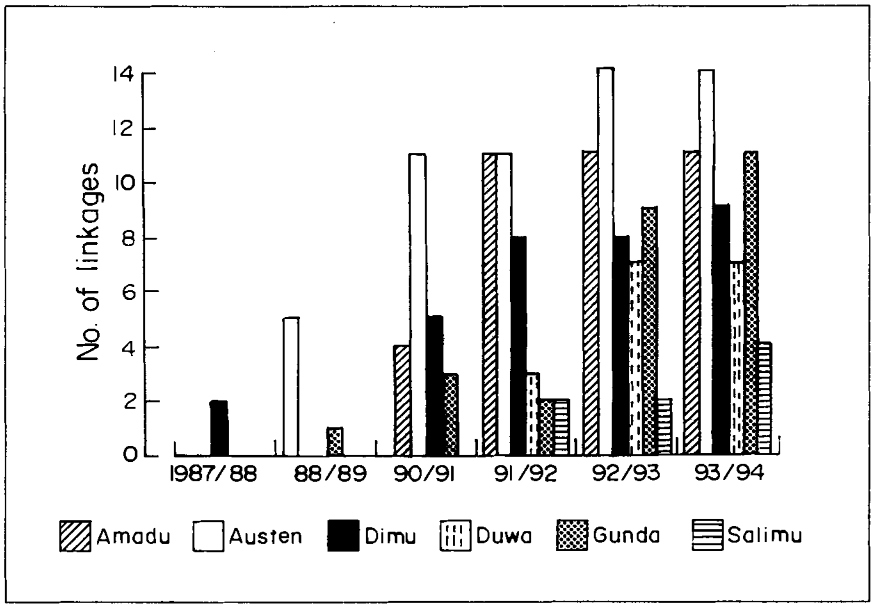


Fig. 5.16. Amount of materials being recycled among enterprises on six farms in Chinseu, Zomba District.

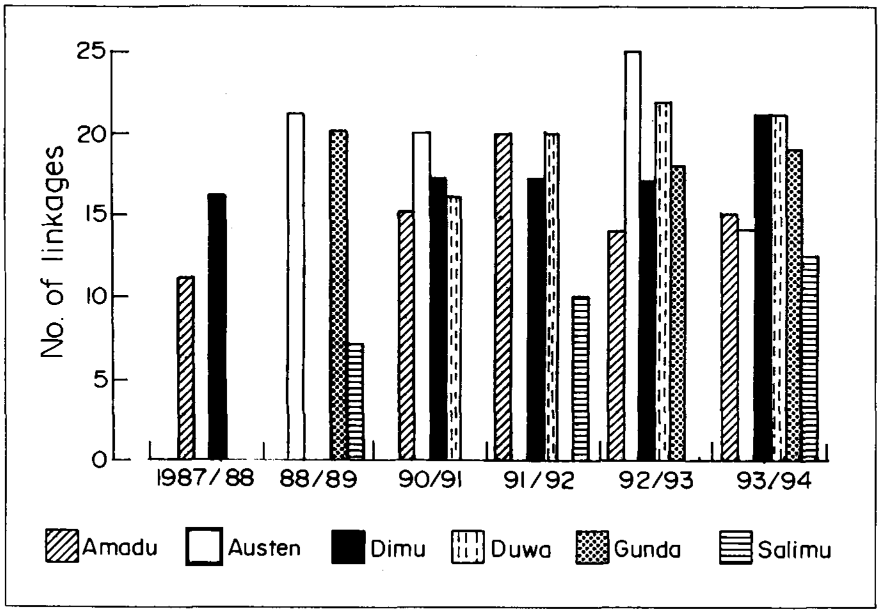


Fig. 5.17. Crop and livestock diversity on six farms practicing aquaculture in Chinseu, Zomba District.

*dimba* garden, thereby extending its growing season and productivity. Introducing aquaculture did not affect the diversity of enterprises being operated on the farms as shown in Fig. 5.17.

Ecologically and economically, ponds do have the potential to profoundly affect the sustainability of small farms as witnessed by this preliminary work. All of the farms concerned were badly affected by drought which has been serious since 1991. Yet in all cases, even though *munda* crops failed and farmers suffered economic losses, the pond-*dimba* systems kept operating and sustaining the farms through the drought. By retaining water on the land, ponds have enabled farmers to sustain their food production and balance their losses on seasonal crop lands.

The conclusions from this work is that small farms do benefit from low-input, small-scale aquaculture if it is integrated with other farm activities. Ponds enable marginal land to be brought into production and increase its value in cash and food production significantly compared with other resource types on farm. Ponds integration with crops, livestock, etc., stimulate more intense use of bioresidues thus increasing recycling of bioresources. This reduces need for expensive off-farm inputs and should help to improve overall farm economics as well as contribute to more ecologically efficient management.

All of these changes are wrought by the farming families themselves with facilitation by researchers. Really that is the crux of the matter. Sustainability of aquaculture is only feasible for small-scale farms in Africa if farmers play the leading role in designing the systems. In all of the examples mentioned, farmers were given the initial stimulation and they took ideas, modified them, created new designs and evolved sustainable fishpond systems.

# CHAPTER 6

## Research and Development for Sustainable Integrated Aquaculture

Despite the development of a wide range of effective pond management strategies, sustained adoption of integrated aquaculture in the 1988-1990 period remained at levels which were less than the availability of suitable sites would indicate as possible. ICLARM-BMZ/GTZ's collaborating projects, responsible for extending the technology, were using traditional training and visit approaches to reach farmers. Financial resources limited the ability of the Government of Malaŵi to get information from the experiment station into the field. Farmers' clubs were established and group discussion methodologies were utilized to more effectively share information and resources and improve the efficiency of extension, but social factors reduced the effectiveness of these approaches. Mass media outreach was limited by the generally low level of literacy and radio ownership among smallholders.

To determine what role research might play in solving these problems, ICLARM-BMZ/GTZ and its collaborators in Malaŵi began, in 1990, to engage farmers directly as a means of enhancing the efficacy of the farmer-extension-research continuum (Noble and Rashidi 1990). Model integrated aquaculture systems were set up at NAC to demonstrate to farmers the technologies which had been developed (Fig. 4.7). Farmers were invited to attend open days at which these new ideas could be explained and discussed. In five open days during 1990-1991, over 90 local smallholding farmers visited NAC and were exposed to ICLARM-BMZ/GTZ integrated aquaculture technology (Chikafumbwa 1994a).

During the open days, farmers were asked to comment on the technologies which they had seen. To the surprise of the researchers and extension personnel, the farmers, while impressed with the new ideas, were not simply quiet observers but expressed a wide range of intelligent and constructive criticisms of the methods, despite having never been involved in many of the agriculture enterprises on show. Of these farmers, 86% adopted at least one of the demonstrated technologies, 76% adopted at least two and 24% adopted four. 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.

Even more significant was the observation that, once in the rural community, the technology spread and evolved without further extension support. A survey by Noble and Rashidi (1990) found that, within six months of the May 1990 open day, 46% of adopters in the target area had learned about it 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 attended an NAC open day (Chikafumbwa 1994a).

By studying the distribution of adopters relative to farming system type, it was discovered that technologies were more likely to be taken up if they fit easily into ongoing activities and enterprises. If, for example, a farmer was familiar with either rice or fish culture, the adoption rate within one year was 65% against 33% for farmers with no experience with either technology (Chikafumbwa 1994a). In addition, there was no farmer-to-farmer spread of technology in areas with no history of either technology while over 75% of farmers in areas with experience of rice farming gained the technology from other farmers.

These developments led ICLARM-BMZ/GTZ to the realization that, despite efforts to incorporate into the R and D process the information collected in numerous socioeconomic and agroecological surveys, only the farmer knows for sure which innovations might fit into his or her socioeconomic and farming system. For technology to be rapidly and sustainably absorbed into rural communities, the farmers themselves must be incorporated into both the research and extension processes and not be regarded as mere observers and assimilators of information. The traditional method of evaluating the suitability of technology in terms of productivity and cost/benefit without an in-depth understanding of the user group was obviously responsible for the low adoption rates of integrated aquaculture. Clearly, the traditional approach of developing technology on the experimental station and then passing it to extension agents for distribution to farmers needed modification to include: (1) a method for incorporating the farmer into the decisionmaking process; and (2) a means of conducting controlled studies of real farming systems and evaluating results from the farmer's perspective. Chapter 5 dealt at length with the former problem. Here we deal with the latter.

## Farmer-Scientist Research Partnerships

On-farm failure of supposedly appropriate technology is a well-known phenomenon, and is at least partly due to researchers working on experimental stations, having used optimal, rather than realistic, conditions in developing extension packages. This is especially true for integrated agriculture-aquaculture research where the test situations, due to the requirements of controlled experimentation, are almost always drastically simplified versions of real mixed farming systems. Of the typical range of dozens of crops, only two or three are generally tested in classical on-station research and development.

The impact and effectiveness of new technology is also not so simple to measure as is generally supposed. In aquaculture research for example, individual fish growth is generally taken as an indicator of success. This has been the driving force behind the indiscriminate translocation of exotic species with allegedly superior performance (equated with growth rate). In small farming systems, however, many other parameters are at least as important as growth rate. Brummett (1994b) pointed out that purchasing power in rural Malaŵian communities is severely limited. Also, in Southern Malaŵi, fish are sold purely by weight; 1 kg of 20 g fish fetches the same market price as a single 1 kg fish (Brummett and Katambalika, in press). In this situation, producing many small fish is more lucrative than a few larger ones, since few opportunities to sell large fish are available. Carrying capacity of small ponds stocked with small fish is greater than that for large fish; a system which produces many smaller fish returns a better profit.

Other methods are also subject to large error. As Harrison (1994) learned in Zambia, fishponds are built for a wide variety of reasons rendering the connection between pond construction and adoption of fishfarming problematic. Measuring the appropriateness of aquaculture technology requires that the entire farming system, both internally and within the context of the local market, be evaluated to be sure that the proposed solutions address the real situation.

While it is virtually impossible to conduct controlled scientific experimentation on whole farms unless you take them apart, on-station research might be made more realistic by managing the experimental units as much like the farm as possible. To do this requires:

1. an in-depth understanding of how the actual farming system functions;
2. a user-friendly method of introducing new technology to farmers;
3. a method whereby the management strategies used by farmers, which are not the same on any two farms, can be simulated on the station;
4. using (3), a method to conduct controlled research permitting the investigation on new hypotheses which can be tested by farmers.

Socioeconomic and agroecological surveys, coupled with flow model data collected as described in Chapter 5 on over 30 cooperating farms, gave researchers the information needed to begin designing potential integration technologies at NAC. The technologies developed are described in Chapters 3 and 4.

With these technologies in hand, two research projects were planned. The first was to examine how farmers used and modified proposed technology using established fishfarms with perennial water supplies. The second was aimed at new entrants in strictly rainfed areas to determine the ecological limitations to adoption of integrated aquaculture.

## Aquaculture Integration

During the period 24 February-18 March 1993, seven farm ponds and eight ponds at NAC were stocked with a mixed-sex polyculture of *Oreochromis shiranus* and *Tilapia rendalli*. Pond areas and fish stocking data are shown in Table 6.1. Each farmer had a different size of pond and selected a different stocking rate and a different initial size of fish. The pond areas at NAC are 200 m$^2$, 18.6 m$^2$ smaller than the average farmer's ponds. Stocking weights and numbers in four ponds at NAC were based on averages of those used by farmers. Four additional ponds at NAC were stocked with fish of the same average weight, but at half the density in order to estimate pond carrying capacity. Fish were sampled every 30 days until harvested after an average of 149 days (range 137-158 days).

Fig. 6.1 shows sampling and harvest individual weight data. Average weights were not significantly different ($P<0.05$) in farm and station ponds which were stocked at the same rate. *O. shiranus* averaged 35.8 g on-farm and 29.7 g on-station; *T. rendalli* averaged 31.6 g on-farm and 28.7 g on-station. As with average weight, the total weight of reproduction, total standing stock at harvest and net yield were the same ($P<0.05$) on-farm and on-station. Complete pond harvest data are reported in Table 6.2.

Ponds which were stocked with only half the number of fish used by farmers produced fish of the same average weight as the other two treatments. *O. shiranus* averaged 43.3 g and *T. rendalli* averaged 35.8 g. Reproduction was the same across treatments while survival was higher in the more lightly stocked pond. This led to a situation where the final fish density was, by the end of the production period, statistically the same in all ponds. The identical standing stocks and yields would normally indicate that the mortality in the farm

Table 6.1. Stocking data for farmer participants and NAC research ponds in an on-farm/on-station integrated agriculture-aquaculture production trial in Southern Malaŵi.

| Pond | Pond area ($m^2$) | Stocking date | *Oreochromis shiranus* (no.·$m^{-2}$) | Average weight (g) | *Tilapia rendalli* (no.·$m^{-2}$) | Average weight (g) | Total no. (per $m^2$) | Total weight stocked (kg·200 $m^2$) |
|---|---|---|---|---|---|---|---|---|
| Amadu | 292.7 | 10 March | 1.4 | 4.0 | 2.4 | 3.4 | 3.8 | 2.8 |
| Dimo | 283.0 | 25 February | 0.7 | 7.0 | 1.2 | 4.9 | 1.9 | 2.2 |
| Kassim | 194.2 | 4 March | 1.0 | 4.7 | 1.8 | 4.0 | 2.8 | 2.4 |
| Phiri | 199.1 | 5 March | 1.0 | 5.1 | 1.8 | 4.8 | 2.8 | 2.8 |
| Salimu | 227.0 | 26 February | 0.9 | 7.2 | 1.5 | 5.8 | 2.4 | 3.0 |
| Samu | 170.5 | 2 March | 1.2 | 4.9 | 2.1 | 4.1 | 3.3 | 2.9 |
| Twaibu | 241.0 | 24 February | 0.8 | 7.5 | 1.5 | 4.9 | 2.3 | 2.7 |
| Average | 218.6 | 3 March | 1.0 | 5.8 | 1.76 | 4.6 | 2.76 | 2.66 |
| Pond 48 | 200 | 1 April | 1.0 | 6.3 | 1.76 | 4.6 | 2.76 | 2.88 |
| Pond 49 | 200 | 1 April | 1.0 | 5.9 | 1.76 | 4.7 | 2.76 | 2.83 |
| Pond 50 | 200 | 1 April | 1.0 | 6.1 | 1.76 | 4.0 | 2.76 | 2.63 |
| Pond 51 | 200 | 1 April | 1.0 | 5.5 | 1.76 | 4.3 | 2.76 | 2.61 |
| Average | 200 | 1 April | 1.0 | 5.95 | 1.76 | 4.4 | 2.76 | 2.74 |
| Pond 43 | 200 | 18 March | 0.5 | 6.1 | 0.88 | 4.9 | 1.38 | 1.47 |
| Pond 44 | 200 | 18 March | 0.5 | 5.2 | 0.88 | 4.2 | 1.38 | 1.26 |
| Pond 45 | 200 | 18 March | 0.5 | 5.1 | 0.88 | 4.3 | 1.38 | 1.27 |
| Pond 46 | 200 | 18 March | 0.5 | 6.0 | 0.88 | 4.7 | 1.38 | 1.43 |
| Average | 200 | 18 March | 0.5 | 5.6 | 0.88 | 4.5 | 1.38 | 1.36 |

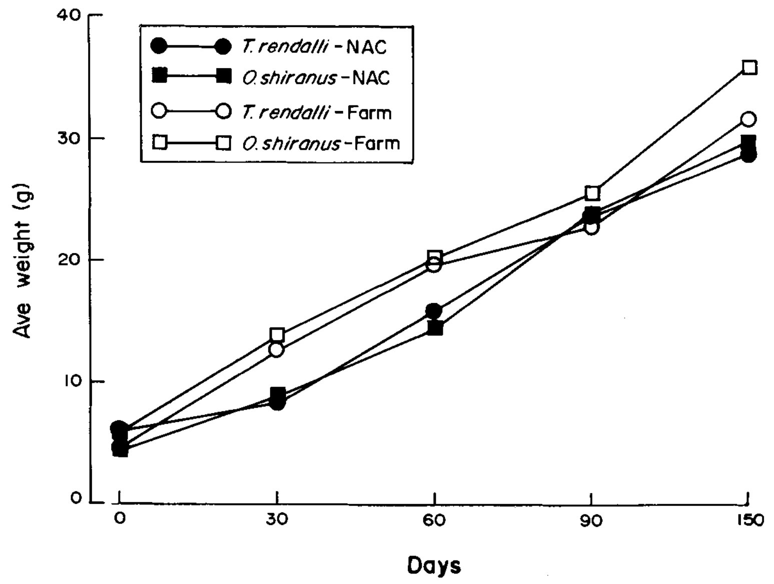


Fig. 6.1. Comparison of individual fish growth on-farm and on-station from a 1992-1993 research and development project. Farm values represent the mean of seven farmers while NAC values, of four replications.

and higher density station ponds must have occurred early in the production cycle. However, the high variances and tendency in Malaŵi of ponds to be robbed or partially harvested early might also indicate that mortality (i.e., reduction of fish density) may have occurred somewhat later than a strict statistical interpretation would indicate. This supposition is supported by the observation that final average weights between heavily and lightly stocked station ponds were approaching significance in their differences: at $P = 0.01$, they are significant.

A comparison of the production figures from the three treatments reveals that the half-yearly yield appears to be at or around 550 kg·$ha^{-1}$ for these systems regardless of stocking

Table 6.2. Culture periods and harvest data for a polyculture of *Oreochromis shiranus* and *Tilapia rendalli* grown on-farm and on-station for 149 days under farm conditions. All averages within columns are statistically identical ($P<0.05$).

| Pond | Culture period | *Oreochromis shiranus* | | | *Tilapia rendalli* | | | Total weight of reproduction[a] (kg·200 $m^2$) | Total standing stock (kg·$ha^{-1}$) | Net yield (kg·$ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|---|
| | | No. > 100 mm (per 200 $m^2$) | Total weight (kg·200 $m^2$) | Average weight (g) | No. > 100 mm (per 200 $m^2$) | Total weight (kg·200 $m^2$) | Average weight (g) | | | |
| Amadu | 147 | 180 | 5.7 | 31.7 | 160 | 5.4 | 33.8 | 10.3 | 1,070 | 930 |
| Dimo | 158 | 120 | 5.0 | 41.7 | 160 | 4.7 | 29.4 | 5.4 | 755 | 645 |
| Kassim | 137 | 140 | 4.1 | 29.3 | 60 | 1.9 | 31.7 | 7.5 | 675 | 555 |
| Phiri | 138 | 140 | 3.7 | 26.4 | 40 | 1.0 | 25.0 | 4.0 | 435 | 295 |
| Salimu | 150 | 80 | 4.2 | 52.5 | 200 | 6.6 | 33.0 | 6.5 | 865 | 715 |
| Samu | 158 | 80 | 3.0 | 37.5 | 20 | 0.7 | 35.0 | 1.7 | 270 | 125 |
| Twaibu | 153 | 80 | 3.4 | 42.5 | 160 | 5.1 | 31.9 | 4.6 | 655 | 520 |
| Average | 149 | 117.1 | 4.2 | 35.8 | 114 | 3.6 | 31.6 | 5.7 | 675 | 541 |
| Pond 48 | 149 | 111 | 2.9 | 26.4 | 121 | 3.7 | 30.3 | 6.6 | 660 | 516 |
| Pond 49 | 149 | 187 | 6.0 | 31.8 | 210 | 7.1 | 34.0 | 5.7 | 939 | 798 |
| Pond 50 | 149 | 99 | 2.8 | 27.9 | 243 | 5.8 | 23.9 | 3.3 | 593 | 462 |
| Pond 51 | 149 | 143 | 4.7 | 32.8 | 192 | 5.1 | 26.7 | 5.3 | 756 | 626 |
| Average | 149 | 135 | 4.1 | 29.7 | 192 | 5.4 | 28.7 | 5.2 | 737 | 601 |
| Pond 43 | 149 | 89 | 3.6 | 40.2 | 127 | 3.6 | 28.6 | 3.9 | 556 | 481 |
| Pond 44 | 149 | 69 | 2.5 | 35.5 | 144 | 4.1 | 28.4 | 3.5 | 502 | 437 |
| Pond 45 | 149 | 60 | 2.5 | 40.8 | 101 | 5.4 | 53.1 | 5.1 | 646 | 581 |
| Pond 46 | 149 | 51 | 2.9 | 56.5 | 138 | 4.6 | 33.2 | 5.6 | 653 | 583 |
| Average | 149 | 67 | 2.8 | 43.3 | 128 | 4.4 | 35.8 | 4.5 | 589 | 521 |

rate (Fig. 6.2). The continually increasing standing stock in all treatments indicates that the maximum carrying capacity for these ponds was not reached during the production period.

### *Input Simulation*

Weekly sampling of farm input materials began on 4 March and proceeded until 16 July. Sampling involved collecting 100-300 g samples of all materials used since the last sample and asking the farmers how much of what material was introduced into the pond during the interval. Often, the farmer kept track of inputs volumetrically (i.e., in units of baskets or cans per week) and in these cases, the container used to measure inputs was filled and weighed with the various input materials in order to calculate input weight. Potential pond inputs available at NAC were also sampled weekly.

All samples were analyzed for dry matter and nitrogen content. The total wet weight of each material put into each farm pond as well as its dry matter and nitrogen content were then loaded into a spreadsheet. Likewise for data for materials available at NAC. The spreadsheet estimates, from the wet weights of materials recorded as inputs, average total dry matter and total nitrogen fed to the pond per $m^2$ (Table 6.3). These values are then compared to user-generated combinations of materials available on-station to formulate a pond input regime which quantitatively and qualitatively simulates the inputs used on-farm (Table 6.4).

To monitor the impact on water quality of these inputs, water samples for measurement of chlorophyll *a*, total alkalinity, total dissolved solids and total suspended solids were collected weekly from farm and NAC ponds and analyzed in the NAC laboratory.

The input simulation spreadsheet calculated an average input regime which allowed researchers to accurately simulate the on-farm inputs. Figs. 6.3 and 6.4 show the dry matter

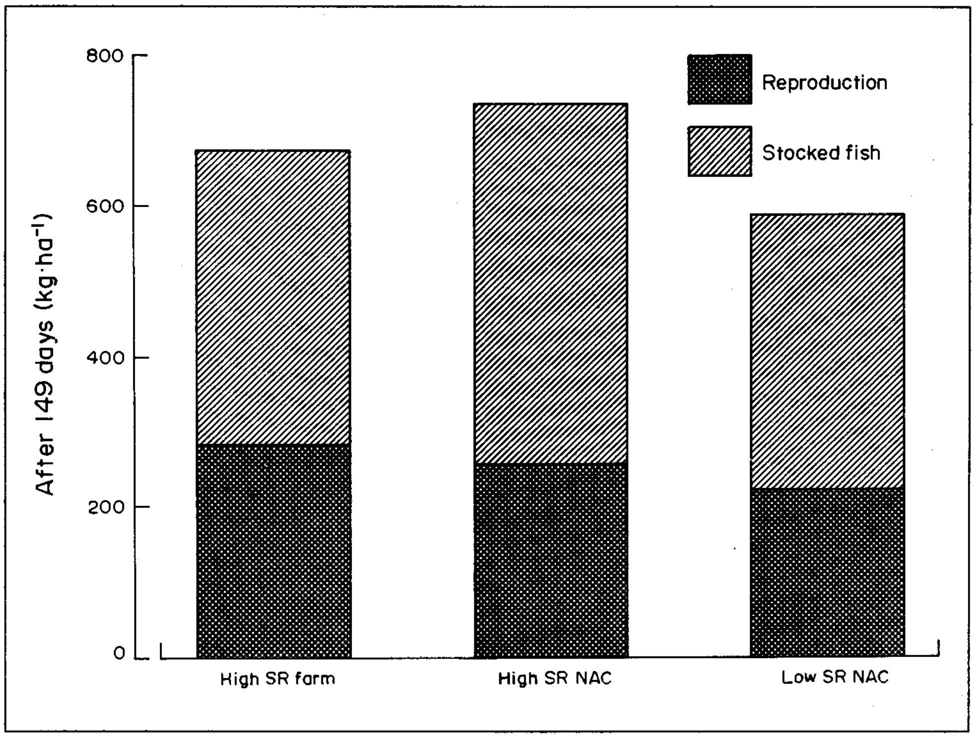


Fig. 6.2. Standing stocks in farm and NAC ponds at two stocking rates (SR) from an on-farm/on-station farmer-participatory research and development project. Farm data are the average of seven farms while NAC, of four replications. High SR ponds were stocked at the same rate as farm ponds; low SR ponds, at one-half the farm rate.

Table 6.3. Average and cumulative farm input data summary generated by an input simulation spreadsheet.

| Day | Average input ($m^2 \cdot day^{-1}$) Wet matter (g) | Nitrogen (g) | Dry matter (g) | Nitrogen (% DM) | DM/WM | Urea equivalent ($g \cdot m^{-2} \cdot day^{-1}$) | Cumulative inputs to date (per $m^2$) Nitrogen (g) | Dry matter (kg) | Wet matter (kg) |
|---|---|---|---|---|---|---|---|---|---|
| 8 | 22.89 | 0.17 | 12.08 | 1.44 | 0.53 | 0.43 | 1.31 | 0.09 | 0.17 |
| 15 | 14.34 | 0.20 | 5.36 | 2.69 | 0.37 | 0.49 | 2.69 | 0.13 | 0.27 |
| 21 | 10.98 | 0.09 | 4.97 | 1.77 | 0.45 | 0.22 | 3.30 | 0.16 | 0.35 |
| 28 | 8.35 | 0.05 | 4.62 | 1.41 | 0.55 | 0.13 | 3.65 | 0.20 | 0.41 |
| 42 | 7.29 | 0.07 | 4.04 | 2.10 | 0.55 | 0.17 | 3.65 | 0.25 | 0.51 |
| 48 | 6.02 | 0.06 | 3.22 | 1.83 | 0.53 | 0.14 | 5.18 | 0.29 | 0.57 |
| 51 | 11.60 | 0.10 | 6.07 | 1.78 | 0.52 | 0.25 | 5.47 | 0.30 | 0.61 |
| 56 | 7.60 | 0.08 | 4.10 | 2.10 | 0.54 | 0.19 | 6.01 | 0.33 | 0.66 |
| 63 | 8.25 | 0.08 | 4.22 | 1.94 | 0.51 | 0.20 | 6.58 | 0.36 | 0.72 |
| 77 | 3.06 | 0.03 | 1.69 | 1.92 | 0.55 | 0.08 | 7.02 | 0.38 | 0.76 |
| 84 | 4.28 | 0.05 | 2.41 | 1.93 | 0.56 | 0.12 | 7.35 | 0.40 | 0.79 |
| 90 | 3.86 | 0.05 | 2.48 | 1.84 | 0.64 | 0.12 | 7.71 | 0.42 | 0.82 |
| 98 | 4.20 | 0.05 | 2.68 | 1.87 | 0.64 | 0.12 | 8.07 | 0.44 | 0.85 |
| 105 | 5.72 | 0.06 | 3.11 | 1.91 | 0.54 | 0.15 | 8.48 | 0.46 | 0.89 |
| 112 | 6.04 | 0.06 | 3.02 | 1.97 | 0.50 | 0.14 | 8.89 | 0.48 | 0.94 |
| 119 | 6.21 | 0.07 | 3.97 | 1.84 | 0.64 | 0.19 | 9.41 | 0.51 | 0.98 |
| 126 | 5.03 | 0.06 | 3.02 | 1.91 | 0.60 | 0.14 | 9.81 | 0.53 | 1.01 |
| 133 | 3.93 | 0.04 | 2.19 | 2.24 | 0.56 | 0.11 | 10.11 | 0.55 | 1.04 |
| 140 | 4.27 | 0.05 | 2.60 | 1.86 | 0.61 | 0.12 | 10.44 | 0.57 | 1.07 |

and total nitrogen inputs used by farmers and researchers. Simulating the inputs results in similar fish production depends upon how the inputs are used in the pond ecosystem. How the pond uses inputs also determines how small ponds should be monitored during production and experimentation. If the overriding importance of the inputs is as a direct fish food,

Table 6.4. User-interactive on-station diet formulation. On-farm input data are collected from Table 6.2 and compared with values generated as the user changes wet inputs.

| Material | Nitrogen (g/kg DM) | DM (%) | Wet matter[a] (kg) | Nitrogen (% DM) | Dry matter (kg) | Nitrogen ($mg \cdot m^{-2} \cdot day^{-1}$) | DM/WM |
|---|---|---|---|---|---|---|---|
| Goat manure | 14.00 | 0.59 | 0.00 | | 0.00 | 0.00 | - |
| Chicken manure | 16.00 | 0.74 | 0.00 | | 0.00 | 0.00 | - |
| Maize bran | 19.52 | 0.65 | 0.70 | | 0.45 | 0.44 | 0.65 |
| Sweet potato leaf | 31.04 | 0.11 | 0.00 | | 0.00 | 0.00 | - |
| Napier grass | 16.32 | 0.31 | 0.50 | | 0.16 | 0.13 | 0.31 |
| *Leucaena* spp. | 33.60 | 0.32 | 0.00 | | 0.00 | 0.00 | - |
| | | | 1.20 | 0.02 | 0.60 | 0.57 | 0.51 |
| | | On-farm: | 1.21 | 0.02 | 0.60 | 0.58 | 0.50 |
| | | Fit[b] | 0.99 | 1.00 | 1.01 | 0.99 | 1.01 |

[a]Sample data from week 14.
[b]The ratio of farm: station inputs.

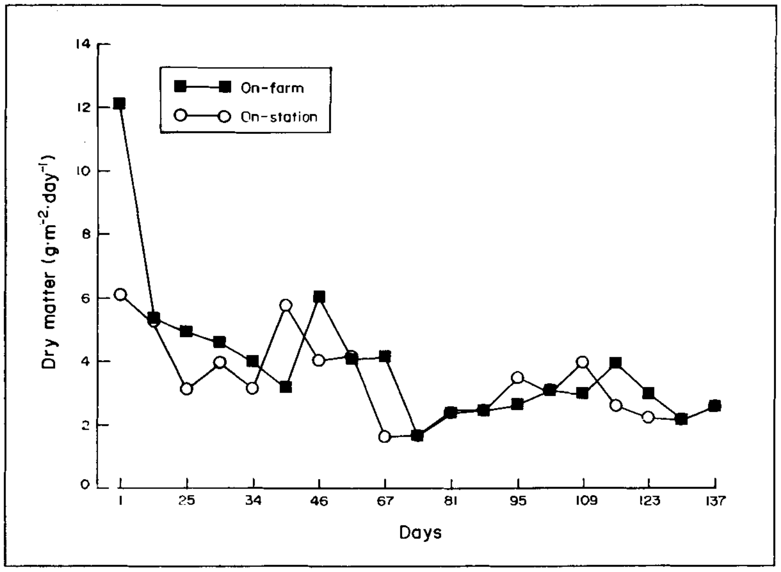


Fig. 6.3. Total dry matter inputs to farm and NAC ponds.

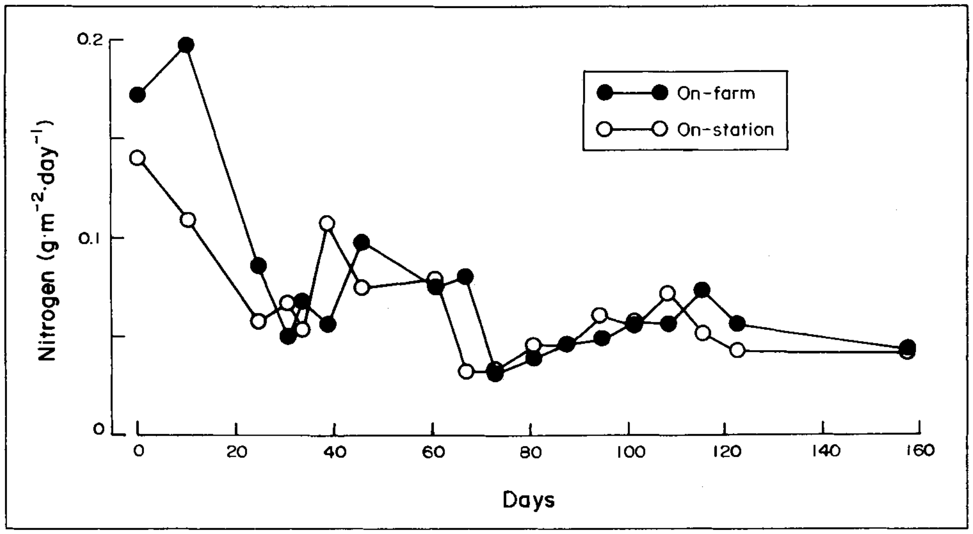


Fig. 6.4. Total nitrogen inputs to farm and NAC ponds during a test of an on-farm/on-station research and development methodology.

then the important water quality parameters might be dissolved oxygen and temperature, since fish do not rely heavily on natural pond food organisms. On the other hand, if inputs are used primarily as fertilizers to feed natural pond food organisms and are only secondarily consumed by fish, then water quality parameters such as chlorophyll *a* and total suspended solids might be valuable indicators of productivity.

In this study, total suspended solids fluctuated widely in both farm and research station ponds (Fig. 6.5). This high variability renders interpretation difficult. It certainly indicates that TSS is highly sensitive to temporary environmental vagaries and might therefore be more useful as an indicator of potentially dangerous short-term trends in water quality than as a predictor of pond productivity over an entire growing season.

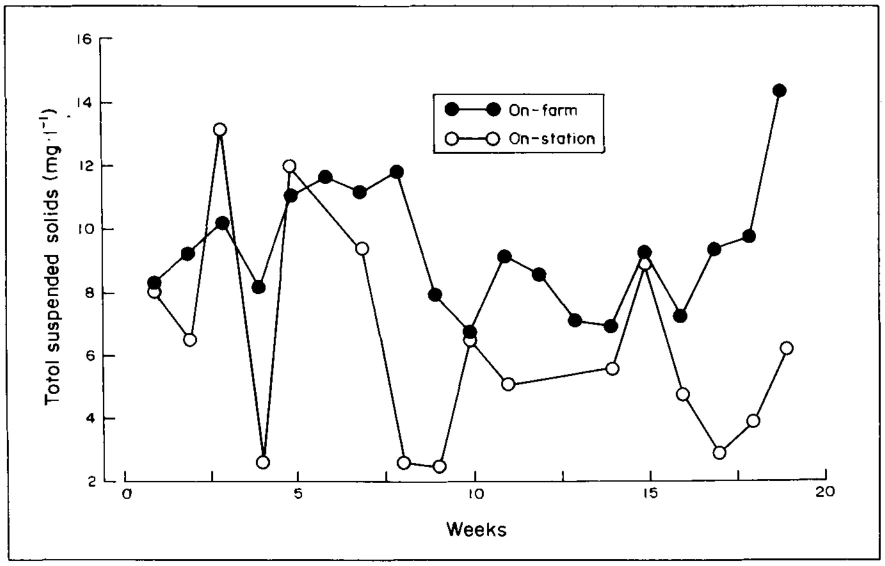


Fig. 6.5. Total suspended solids in farm and NAC ponds during a test of an on-farm/on-station research and development methodology.

Total dissolved solids fluctuated about a mean of 80 mg·l$^{-1}$ on-farm (Fig. 6.6). On-station, TDS was more stable but lower, averaging about 40 mg·l$^{-1}$. Considering the similarity in fish growth between farm and station, TDS clearly would be a poor predictor of pond productivity.

Chlorophyll *a* was very similar between the two data sets (Fig. 6.7). Costa-Pierce et al. (1993a) found that both *O. shiranus* and *T. rendalli* specific growth rates were directly related to dissolved oxygen and inputs of napier grass (*Pennisetum purpureum*) and maize bran. Inversely related to each other in Costa-Pierce et al. (1993a) were dissolved oxygen and inputs. In this study, dissolved oxygen was only measured on-farm during weekly visits which usually took place in the afternoon. It is therefore not possible to determine if the values on-farm might have been different from those measured daily at 0500 at NAC. However, since phytoplankton density (as estimated by chlorophyll *a*) and fish standing stock were similar in both farm and station ponds, and since phytoplankton and fish are the greatest regulators of dissolved oxygen in ponds, it can be assumed that either the dissolved oxygen profiles of farm and station ponds were similar, or that dissolved oxygen is not a useful predictor of pond productivity in these systems.

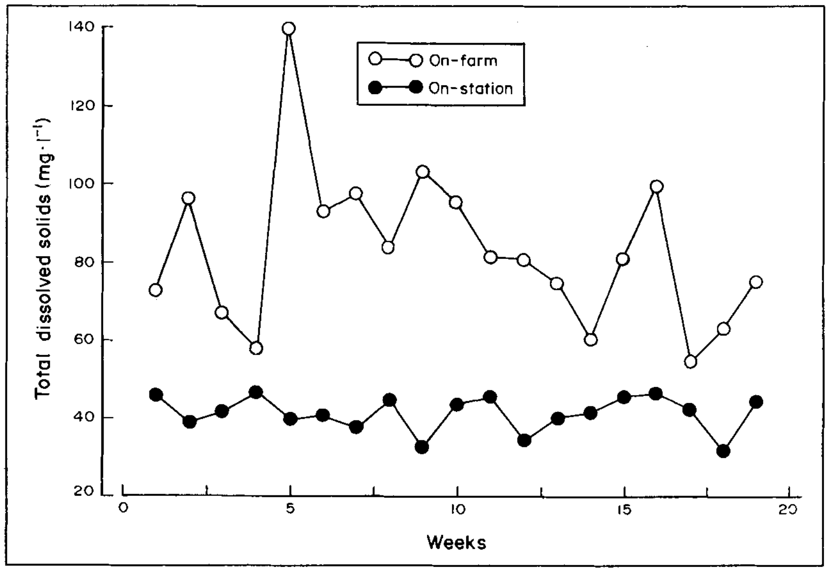


Fig. 6.6. Total dissolved solids in farm and NAC ponds.

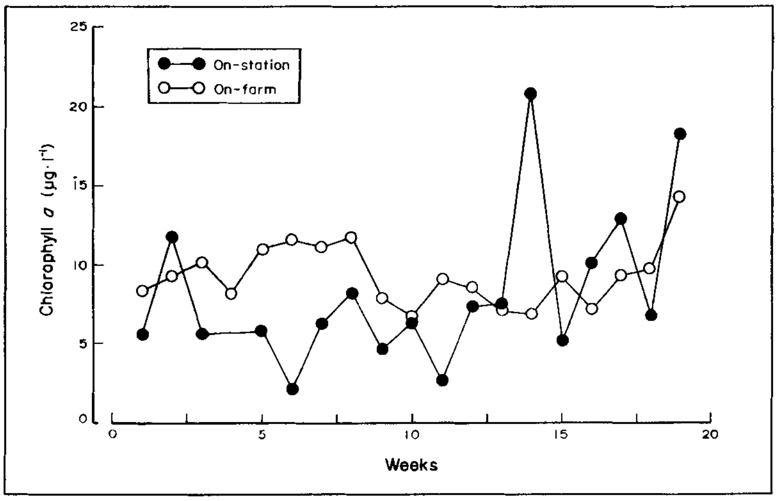


Fig. 6.7. Chlorophyll *a* in farm and NAC ponds.

## Rainfed Aquaculture

Traditionally, the extension of fishfarming technology to rural communities in southern Africa has been largely restricted to those farmers with access to perennial water supplies. The common-property status of Malaŵian *dambo*, the most common type of permanent water source, restricts the ability of individuals to construct fishponds and engage in aquaculture (ICLARM and GTZ 1990; Harrison 1994). Also, whether causal or not, people who can develop such resources are generally those with greater wealth. The insistence by research, development and extension personnel on developing the best sites first has thus led to a distinct slant towards helping "the richest of the poor".

Working with this group has advantages for the extension system. Farmers with greater wealth will tend to be better educated and more innovative, making them more likely to comprehend extension methods and be able to put them into practice.

On the other hand, the majority of potential users of aquaculture technology are not in this group, but belong to the much larger group of landowners without access to permanent water supplies and who, due largely to poverty, are more traditional in their outlook and less well educated. Adoption and transformation of technology might be different among these users. Also, the marginal impact of new technologies on these poorer farms might be greater.

To determine if the research and development methodology described above could be used to direct experimentation at this group of farmers, ICLARM-BMZ/GTZ conducted a pilot study on the adoption of aquaculture in rainfed sites.

### *Fish on Dry Farms*

Through local agriculture extension agents, village headmen in Mtwiche and Sakata areas of Zomba District were contacted in the spring of 1993 to determine the possible level of enthusiasm in these areas for collaboration with a rainfed-pond research project. After consultation with villagers, the headmen introduced ICLARM scientists to nine prospective farmers. Preliminary site surveys disqualified three farmers on the grounds that their proposed sites, being within the *dambo*, were more suitable for permanent than temporary ponds. Water retention time in the six remaining farms was estimated from size of watershed (average 4,200 $m^2$), soil type and observation of the water table, at seven to eight months in a typical year (rainfall of 1,040 mm).

The six farmers (three men and three women) were exposed to the basic concept of integrated agriculture-aquaculture through extensive discussion. The idea put forward was that fish could be grown economically if: (1) only materials which the farmer deems valueless for sale or other uses are put into the pond and (2) farmers put into the pond only the amounts of these materials which can be collected, processed and introduced in his or her "spare time". No other technology was presented.

In prolonged interviews, the research nature of the proposed activity was carefully explained to the farmers. The point of the experiment was to see if the simple methods presented could be effectively implemented at the village level with village means. Researchers also wanted to see how the proposed technology was adapted by smallholders and estimate to what extent it might evolve through farmer-to-farmer transmission. It was made clear that minimal external assistance could be expected other than the provision of fingerlings (to ensure their number, species and quality) and assistance with sampling and harvest (to guarantee the accuracy of the data collected). Rather than presenting aquaculture as a "ready-to-adopt" technology, it was repeatedly stressed that the project might just as easily fail as succeed, and that the results, be they positive or negative, were the property of the farmers themselves.

Pond construction began in August-September 1993, on five sites (one farmer, a single female head of household, dropped out, due to lack of labor to help with pond construction and management). Ponds were dug by hand down into the soil to maximize the residence time of collected rainfall and provide maximal drainage of surrounding cropland. Pond sides were sloped to minimize erosion and guarantee that any children who fell in could escape. Other than providing these guidelines, ICLARM gave no assistance.

Four ponds (one of the male farmers fell ill after pond construction began and was unable to continue work) were completed by the onset of the rains in early December 1993. Ponds averaged 92 $m^2$ in surface area and 1.1 m in depth. Due to low rainfall, the ponds only became stockable at the end of January. On 2-4 February 1994, the ponds were stocked with a 1.5:1 ratio of two indigenous tilapias, *Oreochromis shiranus* and *Tilapia rendalli*, at a rate of 2.5 fish $m^{-2}$. Pond sizes and stocking data are shown in Table 6.5.

To test, under more realistic conditions, new ideas which might be later transmitted to farmers as a second iteration of a general research methodology, the experimental design included parallel testing in ponds managed like the farmers' and control ponds but with a single variable altered. In the trial described above, stocking rate was varied. In this trial, chick-peas were planted into three additional pond bottoms during the dry season prior to the on-farm experiments.

Table 6.5. Stocking data for an evaluation of rainfed aquaculture on farms and at the Malawi NAC. "NAC" indicates control ponds. "Chick-peas" indicates parallel research with chick-peas planted in pond bottoms prior to flooding. Values for the "NAC" and "chick-peas" represent the average of three replicates.

| Farmer | Pond area ($m^2$) | Fish species | Number | Average (g) | Total weight (kg) |
|---|---|---|---|---|---|
| Ng'ombe | 80 | *T. rendalli* | 80 | 12.5 | 1.0 |
| | | *O. shiranus* | 120 | 36.6 | 4.4 |
| Kasichi | 100 | *T. rendalli* | 100 | 17.0 | 1.7 |
| | | *O. shiranus* | 150 | 36.0 | 5.4 |
| Mtikitira | 36 | *T. rendalli* | 37 | 17.6 | 0.7 |
| | | *O. shiranus* | 54 | 38.9 | 2.1 |
| Mtepa | 60 | *T. rendalli* | 60 | 14.2 | 0.9 |
| | | *O. shiranus* | 90 | 36.1 | 3.3 |
| NAC | 200 | *T. rendalli* | 200 | 10.5 | 2.1 |
| | | *O. shiranus* | 300 | 34.6 | 10.4 |
| Chick-peas | 200 | *T. rendalli* | 200 | 8.7 | 1.7 |
| | | *O. shiranus* | 300 | 32.3 | 9.7 |

As described above, ponds at NAC were stocked and managed according to the methods used by the collaborating farmers to serve as on-station controls. Pond bottoms were reworked, lined with fresh surface soil and left dry for three months prior to onset of the rains. As farmponds filled and gradually dried, water level in NAC ponds was regulated to match as closely as possible the average on farm. Pond stocking time and rates were the same as those used by farmers. Input materials and rates used at NAC were based on those of farmers using the input simulation spreadsheet described above.

Due to exceptionally poor rainfall (608 mm), farmponds ran critically short of water and were harvested after an average of only 85 days. One farmpond actually ran dry in-between weekly site visits and was harvested by the farmer without collecting any data.

Harvest data are shown in Table 6.6. Standing stock at harvest averaged 628 kg·ha$^{-1}$. Survival on-farm was low, averaging 67% for *O. shiranus* and 30% for *T. rendalli*, and probably accounted for the low yields. Farmers reported picking up injured fish and seeing fish-eating birds at the pond sites. The situation with birds became worse as the pond level went down. Farmers and researchers agreed that poaching was also a probable factor in low survival.

Production from the parallel chick-pea-planted ponds was variable and inconclusive. The impact of the chick-peas was minimized by the plants having died too early to set fruit. Apparently chick-peas are not suitable for pond bottoms which tend to be moister than surrounding land, at least during the early part of the dry season.

Table 6.6. Harvest data for an 85-day evaluation of rainfed aquaculture in Zomba District, Malaŵi. One farmer, Mr. Mtepa, harvested his pond without informing the research team and without recording harvest data. Values for "NAC" and "chick-peas" represent the average of three replicates.

| Farmer | Pond area (m$^2$) | Fish species | Survival (%) | Average (g) | Standing stock (kg) |
|---|---|---|---|---|---|
| Ng'ombe | 80 | *T. rendalli* | 65 | 23.0 | 1.2 |
| | | *O. shiranus* | 80 | 50.5 | 4.9 |
| Kasichi | 100 | *T. rendalli* | 26 | 31.0 | 0.8 |
| | | *O. shiranus* | 80 | 44.5 | 5.4 |
| Mtikitira | 36 | *T. rendalli* | 0 | - | - |
| | | *O. shiranus* | 40 | 63.0 | 2.2[a] |
| Mtepa | 60 | *T. rendalli* | - | - | - |
| | | *O. shiranus* | - | - | - |
| NAC | 200 | *T. rendalli* | 99 | 26.3 | 5.2 |
| | | *O. shiranus* | 97 | 55.1 | 16.0 |
| Chick-peas | 200 | *T. rendalli* | 77 | 25.9 | 4.0 |
| | | *O. shiranus* | 96 | 58.2 | 16.8 |

[a] Includes 414 fingerlings weighing 0.7 kg. No other pond had reproduction.

The simulation methodology accurately reproduced on-farm conditions. Average weights of both *O. shiranus* and *T. rendalli* were statistically identical ($P<0.05$) on-farm and on-station. Standing stock at harvest and survival of stocked fish were both significantly lower ($P<0.05$) on-farm than on-station, but were probably due to poaching and bird predation, both of which are more tightly controlled at NAC than in the villages.

## A New Research Strategy

While the method described in these two case studies requires refinement, the general strategy might open new avenues of integrated farming research. ICLARM has made an initial attempt at standardizing the methodology (Fig. 1.1). Participatory resource flow modeling leads directly to the formulation of possible integrations which can be tested on-station. These are then packaged in some way. ICLARM uses demonstration at NAC and site visits to other farmers to begin the dialogue between farmers and scientists (Noble and Kadongola 1990; Noble and Rashidi 1990; Noble and Costa-Pierce 1992). Discussion of the proposed technologies leads to a selection of one or a few which the farmers would like to try on their farms. During this interaction, researchers provide limited guidance, only helping the farmers avoid scenarios which will lead to certain failure. The idea is for the farmers to select a production plan which will generate new knowledge for them and the researcher.

Farmers are responsible for the entire experimental setup on their farms. They dig the ponds and provide all of the nutritive inputs and management. The researchers supply only those basic inputs which will insure statistical reliability of the results. For example, ICLARM in Malaŵi provides fish fingerling populations of known age, sex ratio, species mix, variability in individual weight and length, and genetic composition. Without this basic information, interpretation of the results would be impossible.

Once the farmers have decided upon their agenda, replicate ponds on the experimental station are set up as much like the farmponds as possible. Water level and basic chemistry are adjusted. Fish are stocked at sizes, rates and ratios which copy those used by farmers.

Since each farmer's management plan is unlikely to be exactly like his or her neighbor's, pond management at the station may be based on farm averages. A spreadsheet similar to that used by ICLARM can assist in this.

During the production cycle, researchers monitor water quality, input quantity and quality, and fish growth in both farm and station ponds. Parallel studies, such as that used to estimate carrying capacity described above, can be conducted on-station at the same time as the farm control activity to provide additional information on system function. For example, the effects of weediness, different species combinations and drying have been recently compared. Over the course of these trials, researchers gain an appreciation of the realities on the small farm. For example, the number of hours spent each day collecting manure, chopping grass and shoveling maize bran is often overlooked by researchers who use bags of pelleted fish food.

Working in this way may represent something of a compromise between rigorously controlled science and pure farmer-participatory on-farm research. If the results are more adoptable and if that adoption results in better long-term sustainability, then the compromise must be said to have been a good one.

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