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Integration of aquaculture into crop–animal systems in Asia☆

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Abstract

The status of integrated agriculture-aquaculture (IAA) in Asia is reviewed, with an emphasis on rural small-scale systems. Existing IAA systems within mixed farming systems are characterised and the economic and ecological role of aquaculture described. The importance of nutrient recycling of otherwise unused waste materials as an important element and a benefit of integration is emphasised. Approaches for new entrants to explore and plan integration on their farms are presented. In comparison to other enterprises, the pond offers relatively greater potential for integration on farms and for flows of nutrients to and from the new enterprise. Opportunities for integration are classified based on nutrient source and system. The role of IAA systems in rural livelihoods and the considerations for IAA under the specific conditions of nutrient-deficient smallholder farms are outlined. The present state of experience in dissemination, uptake and system evolution of IAA farms is reviewed as well as the achieved impacts in Asia, both on the poor and on commercial developments, based on examples from Bangladesh, China, India and Thailand. It is concluded that considerable potential exists for further aquaculture integration in Asia, with notable improvements in the livelihoods of rural small-scale farmers.

Keywords: Asia; Integrated agriculture-aquaculture (IAA); Nutrient recycling; Enterprise diversification; Sustainable livelihoods

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1. Introduction

Aquaculture provided 29% of the global food fish production of 121 million t in 1996 (FAO, 1999). In 1997, Asian countries produced 91% of the global aquaculture production of 36 million t, which is dominated by China (68% by weight and 45% by value) followed by India (5% by weight and 4% by value). Aquaculture has been the fastest growing agricultural sector, with an average annual increase in production of 12% from 1991 to 1997 which, by regional comparison, was led by Asia with an increase of 12.8% over the same period (Pedini, 2000). Of global aquaculture production, 15.1 million t (42%) originated from freshwater of which the major share (42%) was Chinese and Indian carp species (FAO, 1999). The top 10 aquaculture producing countries are in Asia (Pedini, 2000). In China, where fish production has a very long history, the majority of the production emanates from fish ponds of approximately 1 ha in size that are integrated with crop and livestock production (Chen et al., 1995; Mathias et al., 1998). In Asia, a wide range of integrated agriculture–aquaculture (IAA) systems are in use and are mainly practiced in Bangladesh, China, India, Indonesia, Malaysia, Thailand and Vietnam (Pullin and Shehadeh, 1980; Little and Muir, 1987; NACA, 1989; IIRR and ICLARM, 1992; Symoens and Micha, 1995; Mathias et al., 1998; FAO 2000b).

2. Definitions of IAA systems

Integrated aquaculture can be defined within the general definition of integrated farming on the basis of diversification of agriculture towards linkages between subsystems. These lead to synergisms in which "an output from one sub-system in an integrated farming system which may otherwise may have been wasted becomes an input to another sub-system resulting in a greater efficiency of output of desired products from the land/water area under the farmer's control" (Edwards et al., 1988; Edwards, 1998). This implies a reliance on on-farm resources for such recycling activities. A broader definition of integrated farming also includes the use of off-farm resources, such as agro-industrial products and by-products (Little and Muir, 1987). A more recent definition put forward by Edwards (1998) is based on a human livelihoods perspective and an expected increase in expansion towards periurban areas, with increased linkages between different farms and specialised agroindustries. Integrated farming involving aquaculture is defined as concurrent or sequential linkages between two or more human activity systems (one or more of which is aquaculture), directly on-site, or indirectly through off-site needs and opportunities, or both.

Linkages between aquaculture and human activities involve not only agriculture (crops, livestock, irrigation dams, canals) but also include roles in sanitation (nightsoil, septage or other forms of human excreta re-use; sewage treatment), nutrient recovery (hydroponic-fish, breweries), and energy recovery (culture in heated effluents of power plants, dairies, etc.). Taking a wider perspective, integration has been viewed as part of Integrated Resources Management (Lightfoot et al., 1993a; Lightfoot and Pullin, 1994, 1995; Pullin and Prein, 1995; Pullin, 1998) with relevance at landscape and/or watershed level.

3. Role in mixed farming systems

IAA farming systems, with aquaculture as a major or minor component of crop- or livestock-based farms, differ greatly from extensive or intensive fish farms that are stand-alone enterprises. Stand-alone fish farms are risky ventures and are not an option for resource-poor farmers in developing countries. For large-scale agri-businesses, stand-alone fish farms are successful both in developed and developing countries, focusing on high-value species that are often export commodities. They are operating at high levels of energy and capital intensity, high levels of risk (e.g. diseases, water quality, price fluctuations, often low profit margins) and require high levels of know-how. Negative effects such as pollution, environmental destruction, and a reliance on pelleted feeds have tainted the image of the industry (Pullin et al., 1993; Naylor et al., 2000).

Integrated farming systems are often less risky because, if managed efficiently, they benefit from synergisms among enterprises, a diversity in produce and environmental soundness (Lightfoot, 1990; Pullin, 1998; Prein et al., 1998). On this basis, integrated systems were suggested as the model for the development of aquaculture by small-scale rural farmers in developing countries (Pullin and Shehadeh, 1980). Various two-component livestock/fish and crop/fish systems designed by scientists often performed impressively on research stations (e.g. Hopkins and Cruz, 1982; Edwards, 1983). On-farm performance was often successful, though not sustainable in large-scale commercial operations, but mixed (if not a failure) on rural smallholder farms (McClellan, 1991; Edwards et al., 1996; Edwards, 1998). The systems design and the technical performance were geared towards maximisation of fish production. Other elements of the smallholder farms and existing social and economic conditions were not considered.

The purposes of integration on and between farms are: increased diversification, intensification, improved natural resource efficiency, increased productivity, and increased sustainability (Lightfoot et al., 1993a; Prein et al., 1995; Devendra, 1997; Dalsgaard and Prein, 1999; ICLARM, 2000).

3.1. Characteristics of IAA systems

Previous technical descriptions of IAA systems focused on two general groups of systems (Pullin and Shehadeh, 1980; Little and Muir, 1986). Firstly, simple integrated systems with two sequentially linked components, either animal-fish or crop-fish. Secondly, multi-component integrated systems with three or more linked components, also utilising commercial inorganic fertilisers and formulated pellet feed. In all of these systems, organic fertilisers are considered complementary to, or alternatives, to inorganic fertilisers, and are geared to induce natural food production (i.e. algae, detritus, benthos) in the ponds (Kwei Lin et al., 1997; Knud-Hansen, 1998). An added advantage is the provision of CO_2 if the pond water is of low alkalinity (i.e. is not limed). These systems have been shown to be cost efficient given the non-utilisation of wastes on and off-farm (Edwards, 1998).

The essential characteristic of IAA systems is the flow of nutrients between enterprises i.e. wastes from one enterprise become inputs to another to increase production. These wastes do not flow exclusively to the pond, but from the pond to other enterprises (in the form of pond mud and nutrient-rich water) such as vegetable production around the pond. Some new enterprises and flows may only have been feasible through introduction of the pond.

Increased enterprise diversity provides opportunities for more nutrient linkages, and a possibility to meet increased nutrient requirements for enhanced production, although this requires additional labour. This opens avenues for on-farm or concurrent integration, both on small-scale farms and in large-scale commercial agribusinesses, with manure and fish production taking place on the same farm. At the community level, diversification leads to opportunities for off-farm integration (i.e. between-farm) such as the sale of chicken manure by poultry growers to specialised fish farms.

Mis-matches can exist which are then major obstacles for increased levels of efficiency and production:

1. Temporal mis-matches: in some environments, residues from crop harvests as pond inputs are available for only short periods in the year, but are needed in seasonal ponds at a different time of the year. This means that farmers do not have the necessary nutrients to fertilise their ponds when needed, resulting in much lower fish production than would be possible if these on-farm plant residues were available when required (R. Brummett, personal communication).
2. Spatial mis-matches: often small-scale rural farms are fragmented with homesteads, crop plots and lowland fish ponds not in convenient proximity for easy transport of crop wastes, kitchen scraps and manures to the pond. Additionally, theft of fish from unguarded ponds located away from the homestead is a common problem.
3. Technological mismatches: in functioning agri-businesses with two-component livestock-fish farming systems, improved livestock breeds are produced in feedlots at high input levels of feed, energy and capital, whilst fish are produced as a secondary crop taking advantage of the 'on-tap' availability of nutrient-rich manure. On the other hand, for rural smallholder farms that are crop dominated with few, often non-penned livestock, on-farm manure production is often an insignificant nutrient source for fish ponds (Edwards, 1998).

A key to the successful operation of integrated farming systems is the orchestration of the multi-enterprise production calendar in such a co-ordinated manner, that residues from one enterprise are available at the right time and in the right amounts needed as inputs to other enterprises. On the other hand, smallholder farms are usually nutrient-starved and farmers focus their efforts on the successful production of the staple crops. Other elements of the farm, such as unconfined livestock, have to survive on what feed resources they can find.

4. Tools for successful integration

A participatory technique, the Bio-resource Flow Diagram (BRFD), was developed to enable the farmers to identify unused resources as nutrient sources and to visualise their use as inputs, e.g. to fertilise fish ponds (Lightfoot et al., 1991b; Noble et al., 1991; Lightfoot et al., 1994). Additionally, the BRFD can be used by farmers to visualise the adoption and integration of a new enterprise, such as a fishpond, into their existing farming system. The BRFD of a farm (Fig. 1) is a picture of the natural resource types, drawn as topographical cross-sections of land and water resources. The enterprises conducted on them are drawn as icons and the farm-generated by-products and wastes that flow from one enterprise to another are drawn as arrows, such as manure to crops, rice bran to pigs, vegetable leaves and chicken droppings to the fish pond. Such recycling flows are defined as intentionally directed flows of resources emanating from one enterprise and contributing to the production of another after being moved there. Recycling does not include product (e.g. grain) flows to market or to household consumption, except where household wastes (e.g. kitchen scraps, cooking ash and nightsoil) are recycled. Similarly, external inputs to fields such as inorganic fertiliser are not included because they do not depict recycling. Bio-resource flows can be depicted and quantified in several currencies such as biomass, nitrogen, energy (Dalsgaard, 1997; Dalsgaard and Oficial,

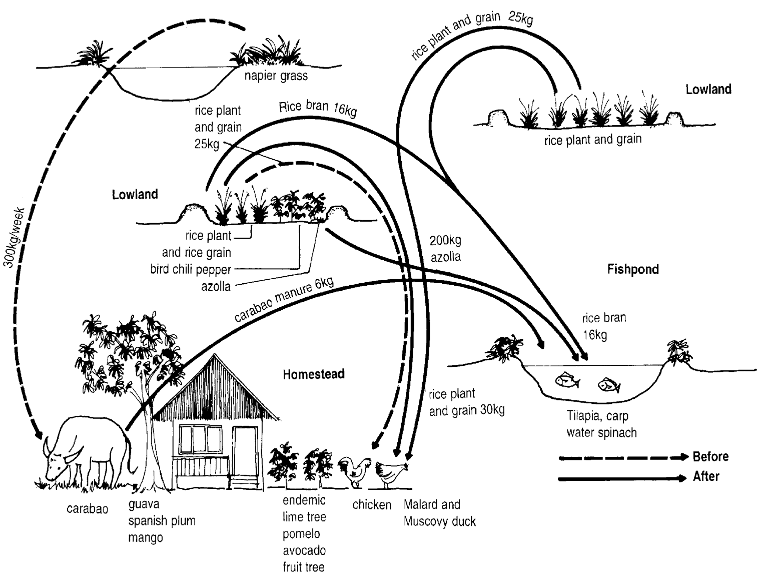

Fig. 1. Bio-resource flow diagram of a farm before (dotted line) and after (continuous line) integration of a fish pond enterprise into the farming system.

1997; Dalsgaard and Prein, 1999) and cash (Lightfoot et al., 2001). When discussing the BRFDs with farmers, biomass as a unit has been found to be most useful.

5. Integrated aquaculture systems and technologies

Generally, two basic types of approach exist. The first, in which a pond enterprise is added to a farm system, and receives nutrient inputs from other on-farm or off-farm sources. These farms can be very complex and have many sources and linkages, particularly in smallholder systems. The other approach is where an aquaculture activity is physically integrated into another enterprise through a modification of the design and operation of the latter, such as fish culture in rice fields.

Existing integrated systems are operated over the entire spectrum of scales ranging from small to large-scale systems that are fully market oriented. In small-scale systems part of the production (in some cases all of it) is for subsistence purposes with some level of market involvement or at least community exchange. In such systems, the aquaculture enterprise is only a minor component of the farm. With greater farm specialisation and market orientation, the aquaculture enterprise can become dominant (e.g. producing specific species and sizes, or operating small hatcheries or nurseries) and supply specific target markets (e.g. in peri-urban settings).

Ponds need inputs in order to be productive and usually greater amounts of inputs are required for economic viability. This requirement for nutrient inputs is a problem for new-entrant smallholder farmers who do not have the resources to purchase fertilisers or formulated fish feeds (in many cases, in developing countries, fish feeds and even inorganic fertilisers are not available in rural areas at affordable costs). Therefore, the obvious entry-point for these smallholder farmers is to use any existing on-farm wastes as pond inputs, which are usually from plants and seldom from livestock. Medium-sized and larger farmers usually purchase from off-farm sources inputs such as grasses, manures and inorganic fertilisers, and even supplement these with fish feeds in the form of grains and formulated pellets.

Fertilisation pathways around and in the pond start from plant waste or manure entering the water, followed by decomposition by pond micro-organisms and the development of natural fish food in the pond such as phytoplankton, zooplankton, benthic organisms and detritus (Colman and Edwards, 1987; Kwei Lin et al., 1997; Knud-Hansen, 1998). The following gives a brief overview of IAA options, whereby a classification according to linkages (e.g. grass-fish or chicken-fish systems) has been intentionally avoided in favour of a classification according to input sources more commonly used in Asia.

5.1. Plant-based sources of pond inputs

Plant inputs into fishponds are also termed green-manures, that are usually aquatic or terrestrial macrophytes (Edwards, 1998). Nutrient content and availability varies between different farm crops and those planted specifically for use as direct fish feed or as pond fertilisers. Those with high nitrogen contents are usually used as pond inputs (Knud-Hansen, 1998). Legumes have a high nitrogen content and farmers have to decide if they are to be used as pond fertiliser or directly as fish feed.

5.1.1. Grass

Grass-fed fishponds are in use mainly in China and Thailand (IIRR and ICLARM, 1992; Gartner and Aguirre, 1997). Although grass material will decompose and provide nutrients in the pond, its utility can be much enhanced through the role of herbivorous fish such as the grass carp (*Ctenopharyngodon idella*) in a polyculture for processing of raw plant material. Their poorly-digested excreta serve as fertilisation for the pond ecosystem and also as direct feed for other fish species. In China, the grass carp is the principal species in high production pond systems using fish polyculture. Grass is purchased from off-farm sources and constitutes the greatest proportion of pond input expenditures in these elaborate systems (Chen et al., 1995). Also, for smallholder farms, the inclusion of grass carp in a specific role of a 'grass bio-processor' enables the use of near-pond grass sources and leads to marked increases in overall fish production.

5.1.2. On-farm plant wastes

The use of on-farm plants and crop residues in fishponds is the common entry-point for smallholder farmers, as these usually do not have penned livestock as constant manure sources. Plants can be native forages or cultivated crops. A point of concern is the necessary synchrony between seasonal availability of residues and the need for these in adequate amounts and quality at the appropriate time in seasonal ponds. If there is a mis-match, the possible amount of nutrient inputs to the ponds will be much restricted and will lead to low fish production. In China, compost is specifically produced for use as in large-scale pond operations. However, this is only possible on multi-enterprise farms or where larger farms are integrated.

The term 'agroforestry-fish' is used for fishponds where leaves of leucaena (*Leucaena leucocephala*) from agroforestry plots (e.g. woodlots, hedgerows) adjacent to ponds are applied. The leaves can be used both as a fertiliser and as direct fish feed.

5.2. Animal manure and offal

Animal-based nutrients applied to ponds are classified generally into either non-livestock or livestock sources. In consideration of important differences in manure quality for pond fertilisation, livestock manures are further grouped according to whether they originate from poultry (mainly chickens and ducks), ruminants (cows, buffalo, sheep, and goats) or pigs.

5.2.1. Non-livestock sources

A well-studied system previously utilised widely in China is the combination of aquaculture and mulberry trees growing adjacent to ponds, in which silkworm droppings and waste pupae are fed into fishponds along with the washings from silkworm trays (Ruddle and Zhong, 1989; IIRR and ICLARM, 1992; Zhong, 1995).

Human nightsoil (e.g. from overhanging latrines above fish ponds and cartage), sewage and septage have a long history of use in Asia (Edwards and Pullin, 1990; Edwards, 1992). Today, their use has diminished in China, but they continue to play an important role in providing nutrients in IAA farming systems elsewhere (FAO et al., 2001).

5.2.2. Livestock manure and offal

Frequently, slaughterhouse wastes are used as fish feed for carnivorous species such as catfish, and as a pond fertiliser. Specialised catfish farms in Thailand utilise chicken offal and processed bones in large amounts.

The most successful operations are those where feedlot systems exist on a commercial scale. These systems produce the large amounts of manure needed to ensure high fish production (Pullin and Shehadeh, 1980; Little and Muir, 1987). However, rural smallholders are not involved in these systems for a variety of reasons (Edwards, 1998). The soluble nutrient contents differ according to animal species and type. Urine is an important nitrogen source, but it is difficult to maintain a regular supply to the pond on smallholder farms. Solid forms of manure also vary in nutrient content as a result of age and mode of storage. Manure is applied fresh and direct or in a dried form having been stored or transported.

Poultry manure is usually of high quality and widely available from specialised intensive poultry farms. The accumulated unused wastes are often put up for sale, but nitrogen loss through drying and storage can lead to lower fertilisation efficiency (Knud-Hansen, 1998). Rural smallholders often face transport problems, as the poultry farms are located around urban areas, and costs for hired vehicles specifically to move manure can be prohibitive. For rural smallholders with free-range backyard systems, the collection of manure is usually not possible.

Manure from ruminants has a low carbon to nitrogen ratio, and is of less use as a pond input unless balanced with alternative nitrogen sources. Urine is a much better nitrogen source, but this is usually lost unless collected through concrete floor slabs or metal/plastic sheeting under slatted-floor pens where animals are kept in confinement. However, in many parts of Asia, ruminants owned by smallholders are communally grazed and are not permanently penned. A major constraint to the widespread use of ruminant manure in fishponds is related to alternative uses as a fertiliser for crops and as a fuel source, particularly in South Asia.

Pig manure is highly variable in quality. Native breeds produce manure of lower nutrient content than improved breeds, but the latter are dependent on high quality formulated feeds and are more susceptible to diseases. Usually, the economics of the pig-fish system depend on the efficiency of the pig production component i.e. feed availability (FAO et al., 2001).

5.3. Aquaculture integrated into other operations

5.3.1. Rice-fish integration

In flooded rice fields, living aquatic resources (LARs) such as fish, freshwater prawns and crabs, snails, mussels and frogs occur naturally. These were regularly caught or collected and have played an important role in the diet of the rural farm households. LARs are small units (easily shared amongst family members in a meal) of readily available (during the rice growing season and on-farm) nutrient-dense foodstuffs (Gregory and Guttman, 1996). In some societies selected species of fish, molluscs and crustaceans have been stocked intentionally to augment the availability and production of protein from rice fields. In floodplain conditions, trap ponds in rice fields, in which wild fish accumulate in the dry season, have been used to extend the holding period of fish with modest feeding (e.g. rice bran) in order to avoid a bulk harvest (Guttman, 1999). In modern times, with the use of pesticides and larger amounts of inorganic fertilisers, the natural occurrence of these LARs has been reduced considerably.

The intentional stocking and culture of fish in rice fields has a long history, particularly in China (Guan and Chen, 1989), with numerous designs and experiences in experimentation and implementation (dela Cruz et al., 1992; dela Cruz, 1994; Halwart, 1994; Cai et al., 1995; Yap, 2001). Usually, a small portion (5–20%) of the area of the rice field is converted into a trench, a refuge pond, or both in combination. Trench layouts vary considerably in their location in the rice fields.

The integrated fish-in-paddy field system functions through the feeding of fish on organisms (particularly insects and other possible rice pests) and weeds, and the stirring of the sediment through their foraging action which leads to nutrient resuspension (Lightfoot et al., 1993b; Cagauan, 1995). It has been observed frequently that rice yields increase through the inclusion of fish (dela Cruz et al., 1992; Cai et al., 1995). As the price of rice has fallen considerably in recent decades, the value of the produced fish can be higher than that of the crop and, thereby, of great importance for additional cash generation by farmers.

The benefits of rice–fish culture as a low-investment entry-level technology for resource-poor farmers has been demonstrated in Bangladesh (Gupta et al., 1998), Indonesia (IIRR and ICLARM, 1992; Purba, 1998), the Philippines (IIRR and ICLARM, 1992; Horstkotte-Wesseler, 1999), and Vietnam (Rothuis, 1998). Presently, rice–fish culture is being disseminated on a large scale in Bangladesh. A recent achievement is the control of the golden apple snail, a rice pest, by the common carp (Halwart, 1998). A beneficial technology for smallholders has been the use of rice fields as nurseries for rearing fish fry to fingerlings during the 3-month rice-cropping period. The fingerlings are then sold at considerable profit (at a size where they are less susceptible to predatory fish) for stocking perennial/undrainable ponds (Little et al., 1991).

Recently, in contrast to the previous examples of individually owned and managed rice fields, a different approach was implemented in Bangladesh and Vietnam for deepwater rice–fish culture in seasonally flooded areas. Trials were conducted with eight groups of landless farmers and landowners in the communal management of seasonally flooded and fenced-off areas which were stocked with fish. Results showed that groups negotiated different sharing arrangements in the season of flooding for fish culture, with benefits for all involved. In the dry season, the areas reverted again to individual management of modern rice varieties (Dey and Prein, 2001; Prein and Dey, 2001).

5.3.2. Trenches in fruit orchards

In the Mekong Delta in southern Vietnam, farmers implement a system of trenches within their fruit orchards, usually surrounded by a lateral trench and a connection to the adjacent rice field (Hien et al., 1998). Fish and freshwater prawns can move between the sub-systems and benefit from the decomposing rice straw, the fallen fruit and from insects dropping into the water. The trenches result from excavations to raise the beds for fruit trees.

5.3.3. Mangroves and brackish water shrimps

The term 'forestry-fish' co-culture is used for the cultivation of brackish water fish and shrimps in fenced-off mangrove forests in Malaysia, the Philippines and Vietnam (Johnston et al., 1999).

5.3.4. Enterprises receiving nutrients from ponds

Where amounts of nutrient inputs to ponds are high and generate ample amounts of nutrient-rich pond sediment, this can be utilised to fertilise crops grown on pond embankments. These cropping areas adjacent to or between ponds, if specifically designed and constructed to rely exclusively on pond mud as nutrient input, can have an area several times larger than that of the original fishpond. The mud and/or water from ponds is used to fertilise vegetables, crops such as sugarcane, flowers, mulberry and fruit trees (e.g. banana, oranges, papaya, lychees, and mangoes). These are often combined with poultry under the trees (Zhong, 1995). 'Bamboo-fish' culture is conducted in China, in which the mud from fish ponds is used to fertilise bamboo plantations grown around the ponds. The waste from the processing of the bamboo shoots is fed into fishponds (IIRR and ICLARM, 1992).

6. IAA systems in poverty alleviation and sustainable livelihoods

6.1. Role in rural livelihoods

Rural small-scale IAA systems already supply an important share of fish used for consumption and income generation by the rural poor in Asia (Kent, 1997; Edwards et al., 2001). Yet, their production is not registered by national services and, therefore, not reported in official statistics. The important role of IAA systems is under-valued and their potential for enhancement usually overlooked in favour of large-scale commercial ventures, which are more attractive for support by development institutions and policy makers (Edwards, 2000; Haylor, 2000).

Numerous examples exist in which aquaculture has been suggested as a technology for poverty alleviation and sustainable livelihoods. Earlier, stand-alone fish farm designs were targeted to benefit poor farmers, but these failed in large-scale development attempts after external support was withdrawn. Similarly, 'simple' two-component packaged systems with a unidirectional flow of wastes (e.g. chicken-fish and pig-fish in pens above or adjacent to ponds), targeted at the rural poor, were also a failure. These systems require operation of the manure-providing enterprise at such high levels of productivity and inputs, that they were neither affordable nor manageable by poor smallholders. An integrated management approach, with flexible and adaptive technology and farmer-participatory design procedures, has proved that farmers can sustainably and beneficially fit a new aquaculture operation into existing traditional crop-livestock farming practices (Pullin and Prein, 1995; Prein et al., 1998, 1999).

In mixed systems on small farms, the motivations for farmers to operate non-crop enterprises are, in order of priority, to reduce risks from cropping; to accumulate capital; in the case of livestock to provide draught animal power and manure for fertiliser/fuel; to satisfy cultural needs; to ensure prestige status; to provide food; and to generate income (McDowell and Hildebrand, 1980). Although products such as fish are eventually consumed or sold, high outputs from the enterprise are often not given adequate attention by the farmers because other services are more important. A newly adopted enterprise must serve multiple purposes. This is why previous single-use extension efforts (e.g. fish exclusively for home consumption) failed to expand widely.

Poor farmers have small land holdings, very limited financial resources and are, therefore, risk averse. Characteristics of suitable IAA technologies are that they should be of low risk to farmers; require low investment; provide quick returns; be simple and easily replicated; provide the capability to establish local fish supply capacity; and easily taught to trainers and farmers (Haylor, 2000). If possible, these requirements should build on local knowledge and the technology should be appropriate to the resource base of the farmers. One of the purposes of aquaculture introduction is to add to the further diversification of mixed farming systems. For such diverse low-input farms, multi-component IAA systems have proved to be viable. Additionally, the fish produced can help to make up for diminishing natural supplies from fisheries in rivers, floodplains and other bodies of water.

6.2. Nutrient management on resource-poor integrated farms

Ponds need nutrient inputs to produce fish. The natural productivity of ponds without external inputs is about 200–800 kg/ha/year, which is unsatisfactory when farmers have other options for use of their labour, land and water resources to increase food supply and income. Higher production can be achieved with greater amounts of nutrient inputs. On small farms these inputs are mainly in the form of wastes from crops and other plants, as farming in Asia is crop dominated and the amounts of livestock wastes available are negligible (Dalsgaard, 1997; Dalsgaard and Christensen, 1997; Dalsgaard and Oficial, 1997). If manure is available, then it is often preferably applied to the fields as fertiliser to enhance the production of staple crops.

Small-farm systems are usually nutrient limited and are not over-fertilised (Edwards, 1993; Dalsgaard and Prein, 1999). They have a high nutrient-use efficiency and economy, as low-input systems cannot produce high volume outputs. However, they can produce high value outputs such as freshwater prawns or small indigenous species which have become scarce.

6.3. Dissemination, uptake and evolution

Indigenous knowledge on aquaculture is limited compared to other farming activities. Aquaculture is very knowledge-intensive and a relatively complex technology for novice farmers to absorb quickly. On the other hand, farmers have good knowledge about the rest of the farm into which a new aquaculture enterprise has to fit. Rural farmers often have good knowledge about natural fish resources if these are traditionally caught as a part-time activity.

Small farms are usually complex, highly organised, efficiently integrated and carefully balanced units. They are operated with the aim of maximising resource utilisation and reducing risk. With existing pressures for change, only the most appropriate technology adjustments and introductions can be successful (McDowell and Hildebrand, 1980). Interventions intended to produce change must be carefully evaluated, otherwise serious imbalances will be created. Experience has proved that it is crucial to invest considerable effort at the beginning of a dissemination effort to diagnose appropriate locations, farm households and farming systems to achieve successful interventions. The diagnostic techniques are based on existing farmer-participatory tools widely used in Participatory Rural Appraisals (Lightfoot et al., 1991a, b; FAO, 2000a; Worby, 2000; Lightfoot et al., 2001). The BRFD, described earlier, is an example of these techniques.

An entry-point has been that of aquatic resources management. Traditionally, rural people have relied on inland fish sources caught on their farms in rice fields or ditches, in nearby water bodies or purchased at low cost from local markets. But, increasingly, these wild aquatic resources have declined due to human population increase and environmental degradation (Guttman, 1999, 2000). Thus, opportunities arise for low-technology enhancement or even the development of culture systems. For example, the productivity of trap ponds can be increased with some stocking, fertilisation and modest feeding of simple inputs (Gregory and Guttman, 1996), even for indigenous small species not originating from hatcheries (Mazumder and Lorenzen, 1999; Felts et al., 1997).

Dissemination has been successful with strong initial support followed by long-term local support to adopters, often provided by non-government organisations in the absence of adequate government extension services. Responsible support institutions need to acquire and maintain the capacity and incentive structures to deliver the required services all the way to the local level. Beyond having to meet the motivational criteria of farmers, mentioned above, the transfer of knowledge in simple formats and absorbable amounts, the participation of farmers in the design of messages, and the facilitation of networking among adopters/producers has been crucial for successful and sustainable uptake of integrated aquaculture by rural farmers (Brummett and Haight, 1996). In Bangladesh, the organisation of 'model pond villages' and farmer groups has led to high rates of sustained adoption (Bland and Griffiths, 1999; Nandeesha and Chapman, 1999). Another approach is that of training fish-fry peddlers to act as disseminators of technology improvements directly to farmers (Lewis et al., 1996; Bland and Griffiths, 1999).

Adopting farmers need to start with simple technologies in the first year. Then, in the coming years, they need to be able to learn gradually and pursue development pathways, in an evolution of their systems, that are incremental. This approach stands in stark contrast to the packaged introduction of totally new and complicated technology, which has usually failed widely. Dissemination efforts need to build initially on basic fish husbandry and pond management skills. For example, by starting with an existing rice field and adding a refuge or trench, or by digging a small pond and starting with a single or a few species with on-farm inputs. On small farms, aquaculture is usually an additional technology; seldom is it an alternative technology that substitutes for an enterprise in an existing farming system.

The observed evolutionary stages of IAA systems are plant residue/manure reliance; increased inorganic fertiliser inputs and low-cost feeds; and some manure and inorganic fertiliser plus aeration and health management. Often in more intensive IAA systems, there is a change in management during a production cycle, e.g. from an initial basis of manure and fertiliser inputs, to a gradual shift to pellet feeding as main input, as is the practice in Taiwan with polyculture at high densities and growth rates. Evolved systems are characterised by product specialisation, market/commercial orientation, off-farm or between-farm integration, and de-integration (i.e. reduction in emphasis on recycling flows) and greater emphasis on inorganic fertilisers and fish feeds, compared to a previous reliance on manure or sewage as the main nutrient sources. These processes have been observed in China and Thailand, together with a trend towards diversification of produced fish into the production of high-value luxury species.

7. Impacts of IAA systems in Asia

7.1. Benefits to the poor

In recent years, a number of studies on the impact of rural IAA systems on household nutrition have been conducted. These show that considerable benefits result either from direct consumption of fish by the producing households or from gains in income which lead to the purchase of other cheaper foods, which nevertheless lead to improved household food consumption (Ruddle and Prein, 1998; Ahmed and Lorica, 1999; Thilsted and Roos 1999, Thompson et al., 1999; Prein and Ahmed, 2000; Sultana, 2000). The high nutritional value of fish, particularly for vulnerable groups such as infants and pre-school children, pregnant and lactating women is widely known (Edwards, 2000), and some societies target specific species as food for these categories (Thilsted and Roos, 1999).

Further direct benefits from rural integrated aquaculture, aside from increased household nutrition and income, are local availability of fresh fish and the provision of employment for household members. Indirect benefits are the increased availability of fish to local and urban markets that may lead to a reduction in prices; increased employment benefits through development of an industry providing work on fish farms and in related services; the development of seed supply networks; the sharing of investment in community-managed common-pool resources such as water bodies, cages, settled/attached species (e.g. freshwater and marine invertebrates and seaweeds); in water storage in farm ponds; and in integrated pest management in rice–fish culture (Edwards, 2000).

The benefits of aquaculture for poor women in rural Bangladesh has been shown to be substantial. In numerous cases, women-headed households have been able to obtain income and achieve tangible levels of relative prosperity (Bedford and Mowbray, 1998). The importance of integrating aquaculture into future rural development programmes has been underlined by NACA/FAO (2000).

7.2. Examples of impacts

In Thailand, beneficial impacts from integrated aquaculture, in terms of household income, were achieved in northeast Thailand through work by the AIT (Little, 1995; Edwards et al., 1996; Demaine et al., 1999). In Bangladesh, major successes have been achieved in recent years through large development activities by the DFID (Bland and Griffiths, 1999), the CARE-Bangladesh (Nandeesha and Chapman, 1999), the DANIDA (Thomsen, 1999), the USAID-ICLARM (Bedford and Mowbray, 1998; Bouis et al., 1998; Gupta et al., 1998, 1999) and the IFAD-ICLARM (Thompson et al., 1999). In India, composite carp culture has been widely successful leading the country to be the second largest aquaculture producer in the world (Nandeesha and Rao, 1989; Veerina et al., 1999; Sharma and Leung, 2000). Additional potential is considered to exist for expansion of rice–fish culture in Orissa and West Bengal.

In China, rice–fish culture is of increasing importance. In 1988, this occupied an area of 700,000 ha producing 120,000 t of fish (Guan and Chen, 1989; Cai et al., 1995), By 1993, the area had increased to 983,000 ha with a production of 230,000 t of fish. In 1994, the area had expanded further to 1.027 million ha and a production of 260,000 t of fish (Liu and Cai, 1998). As a benefit of rice–fish culture, an increase in rice grain yield was reported by Lui and Cai (1998) at levels of 450,000 and 480,000 t in 1993 and 1994, respectively. Pond fish production, which is mainly from integrated systems using carp polyculture, was in the order of 1.0 t/ha in 1983 on large state farms (Guan and Chen, 1989). In the next 10–15 years, the bulk of the marketed freshwater cultured fish came from integrated aquaculture systems on medium-sized holdings, where production ranged from 5 to 8 t/ha/year (Chen et al., 1995). Considerable increases in production efficiency have been reported since then through greater intensification.

The potential impact of genetically improved fish in rural farming systems has been demonstrated for tilapia (Dey, 2000) and several carp species (Dey et al., 2001a, b), whilst the impacts of manipulation of fish sex have been highlighted for tilapia (Cheftel and Lorenzen, 1999).

IAA systems are dynamic over time and are subject to economic and environmental change. The development of aquaculture in China and Thailand has shown the evolution from low-input on-farm integrated systems to high input off-farm integrated and commercial systems supplying significant amounts of fish to rural and urban consumers. On the other hand, the effects of urbanisation and continuous expansion of cities have caused peri-urban systems to be short-lived operations with the added burdens of considerable competition for scarce water, increasing pollution and inflated land values.

In conclusion, substantial progress has been made in the development of IAA systems in Asia. Considerable potential exists for further aquaculture integration within crop-livestock systems in the region, which will contribute to poverty reduction and improvements in the livelihoods of rural small-scale farmers.

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