Culture of fish in rice fields

Edited by

Matthias Halwart
Modadugu V. Gupta

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Contents

Foreword

Rice today is grown in 113 countries in the world in a wide range of ecological conditions and water regimes. The cultivation of most rice crops in irrigated, rainfed and deepwater systems offers a suitable environment for fish and other aquatic organisms. Over 90% of the world's rice, equivalent to approximately 134 million hectares, is grown under these flooded conditions providing not only home to a wide range of aquatic organisms, but also offering opportunities for their enhancement and culture.

The purpose of this review is to synthesize available information and highlight the important role that aquaculture in rice-based farming systems can play for food security and poverty alleviation. Aquatic production, in addition to the rice crop itself, is a critically important resource for rural livelihoods in developing countries; its local consumption and marketing are particularly important for food security as it is the most readily available, most reliable and cheapest source of animal protein and fatty acids both for farming households as well as for the landless.

This review describes the history of the practice and the different rice ecosystems in which fish farming takes place. The various production systems, including modifications of the rice fields necessary for integrating fish farming, and the agronomic and aquaculture management are examined. Pest management in rice has evolved tremendously over the past decades, and the culture of fish and other aquatic organisms can reinforce environmentally and economically sound farming practices.

The real and potential impact of rice-fish farming in terms of improved income and improved nutrition is significant but generally underestimated and undervalued. Hidden benefits of rice-fish farming such as risk reduction through diversification of the farming system may have a strong attraction to many farmers and their families. Fish can be sold directly, or may reduce the dependence of families on other livestock which can then be traded for income. Also, fish from the rice fields may not be sold but the production may be used to feed relatives and those who assist in rice harvesting, a benefit which could almost be considered essential in families with a labour shortage.

The time for emphasizing the importance of rice-fish farming is particularly relevant in light of the currently celebrated UN International Year of Rice 2004.[1] Fish from rice fields have contributed in the past, and continue to contribute today, towards food security and poverty alleviation of many people in rural areas. With significant changes particularly in pest management and fish seed availability taking place in many rice-producing countries, there is now considerable potential for rice-fish farming to further expand its contribution to improve the livelihoods and food security of the rural families.

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[1] The United Nations General Assembly (UNGA) declared the year 2004 the International Year of Rice (IYR) and invited the Food and Agriculture Organization of the United Nations to act as the lead agency for the implementation of the IYR, in collaboration with partners from national, regional, and international agencies, non-governmental organizations, and the private sector. The FAO Fisheries Department with the assistance of Fisheries Officers from the Regional and Sub-Regional Offices contributes to the IYR through various awareness-raising activities related to the importance of aquatic biodiversity in rice- based ecosystems. Information is available at http://www.rice2004.com.

1. Introduction

"There is rice in the fields, fish in the water." This sentence inscribed on a stone tablet from the Sukhothai period - a Thai kingdom that flourished 700 years ago - depicts a scene that must have been as idyllic then as it continues to be now. Having rice in the fields and fish in the water is an epitome of abundance and sufficiency. No other combination would seem to be so fundamental and nutritionally complete in the Asian context. As such, few other plant and animal combinations seem to be more appropriate to culture together to improve nutrition and alleviate poverty. Fish culture in rice fields provides the means for "the contemporaneous production of grain and animal protein on the same piece of land" (Schuster 1955), and in this environmentally conscious age, few other food production systems seem more ecologically sound and efficient.

In the strictest sense rice-fish farming means the growing[2] of rice and fish together in the same field at the same time. However, it is also taken to include the growing of rice and fish serially one after another within the same field or the growing of rice and fish simultaneously, side by side in separate compartments, using the same water. Fish by no means strictly refers to fin-fish. It means aquatic animals living in rice fields including freshwater prawn, marine shrimp, crayfish, crab, turtle, bivalve, frog, and even insects.

Rice-fish farming is practiced in many countries in the world, particularly in Asia. While each country has evolved its own unique approach and procedures, there are also similarities, common practices and common problems.

Global recognition of, and interest in, the potential of rice-fish farming in helping combat malnutrition and poverty has been well known for a long time. The FAO Rice Committee recognized the importance of fish culture in rice fields back in 1948 (FAO 1957). Subsequently it has been the subject of discussions by the Indo-Pacific Fisheries Council (IPFC), the General Fisheries Council of the Mediterranean (GFCM), the FAO Rice Meeting and the International Rice Commission (IRC). IPFC and the IRC formulated a joint program for promoting investigations to evaluate the utility of fish culture in rice fields.

However, international interest gradually waned over the years perhaps due to the use of chemical pesticides and herbicides in the early attempts to boost rice productivity.

It was not until the late 1980s when global interest in rice-fish farming was renewed. Rice-fish farming was identified as a project of the International Rice Research Institute's (IRRI) Asian Rice Farming Systems Network (ARFSN). This project, led by the International Center for Living Aquatic Resources Management (ICLARM), the present WorldFish Center, was implemented as a collaborative effort involving many institutions throughout Asia. At the same time, the International Development and Research Center (IDRC) of Canada co-sponsored China's National Rice-Fish Farming Systems Symposium in Wuxi. The papers presented at the symposium were translated into English and published by IDRC (MacKay 1995). Much of the information on China in this review was obtained from that book.

Over the last 15 years, the spread of rice-fish farming has been uneven and campaigns to promote the practice have often been discontinued. There are a multitude of reasons for this including inappropriate extension campaigns, cheap and readily available pesticides, and lack of credit facilities.

This report seeks to review rice-fish farming as practiced in different countries, explores the similarities and differences, and identifies experiences that may be useful to promote rice-fish culture in other parts of the world. This is not a "how-to" manual; instead it aims to describe how it was done or is being done in various parts of the world.

The report is structured in four main sections and a brief conclusion. After the introduction the first section begins with background information including a brief history of rice-fish culture (Chapter 2) and a description of the rice field ecosystem (Chapter 3). The second section then

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[2] "Growing" is taken to mean the intentional culturing of organisms of either wild or cultured origin.

continues with the system itself with descriptions of modifications needed for fish culture in rice fields (Chapter 4), the various production systems (Chapter 5), the culture techniques and management (Chapter 6), production and yields (Chapter 7), and pest management (Chapter 8). The third section aims to put rice-fish culture in context by discussing its importance to farmers as well as its social and environmental impact (Chapter 9). The fourth section reviews the experiences and status of rice-fish worldwide (Chapter 10) and concludes with the prospects and program for the future and the lessons learned, primarily in Asia, that can be useful in the promotion of rice-fish culture in other parts of the world (Chapters 10-11).

2. History

Both botanical and linguistic evidence point to the early origin of cultivated rice in an arc along continental Asia extending from eastern India through Myanmar, Thailand, the Lao PDR, northern Vietnam, and into southern China. Although the oldest evidence of cultivated rice comes from Myanmar and Thailand, wet rice cultivation[3] involving the puddling and transplanting of rice seedlings is thought to have been refined in China. In contrast to other areas, the history of rice in river valleys and low-lying areas in China is longer than its history as an upland crop.

It can be assumed that once rice farming progressed beyond shifting cultivation in forest clearings to one involving puddled fields with standing water, fish must have been an additional product. Fish and other aquatic organisms would have come in with the flood water, made the rice field their temporary habitat, and grew and reproduced within the duration of the rice farming cycle to become a welcome additional rice field product for the farmers.

It may never be known exactly when or where the practice of deliberately stocking fish in rice fields first started. However, since it is widely acknowledged that aquaculture started early in China, where pond culture of common carp (*Cyprinus carpio*) began at the end of the Shang Dynasty (1401-1154 BC) (Li 1992), it is assumed that rice-fish farming with stocked fish also started in China. Archaeological and written records trace rice-fish culture in China over 1 700 years ago and the practice may have started when fish farmers with excess fry released them in their rice fields (Li 1992; Cai and Wang 1995).

Clay models of rice fields with figurines of common carp, crucian carp (*Carassius carassius*), grass carp (*Ctenopharyngodon idella*), and other aquatic animals date back to the later Han Dynasty (25-220 AD) (Bray 1986, cited in FAO 2000). The earliest written record dates from the Wei Dynasty (220-265 AD) that mentions “a small fish with yellow scales and a red tail, grown in the rice fields of Pi County northeast of Chendu, Sichuan Province, can be used for making sauce.” The fish referred to is thought to be common carp.

Rice-fish culture was first described by Liu Xun (circa 889-904 AD) (Cai et al. 1995) who wrote: “In Xin Long, and other prefectures, land on the hillside is wasted but the flat areas near the houses are hoed into fields. When spring rains come, water collects in the fields around the houses. Grass carp fingerlings are then released into the flooded fields. One or two years later, when the fish are grown, the grass roots in the plots are all eaten. This method not only fertilizes the fields, but produces fish as well. Then, rice can be planted without weeds. This is the best way to farm.”

It is possible that the practice of rice-fish culture developed independently in India and other parts of the “Asian arc” of wet rice farming, but was not documented or circulated. Apart from being described as “an age-old practice” there are few estimates of how long rice-fish farming with deliberate stocking of fish has been practiced outside China, although some authors suggest that rice-fish culture was introduced to Southeast Asia from India 1 500 years ago (Tamura 1961; Coche 1967; Ali 1992).

Integrated rice-fish farming is thought to have been practiced in Thailand more than 200 years ago (Fedoruk and Leelapatra 1992). In Japan and Indonesia, rice-fish farming was developed in the mid-1800s (Kuronoma 1980; Ardiwinata 1957). An early review on rice-fish culture showed that by the mid-1900s it was practiced in 28 countries on six continents: Africa, Asia, Australia, Europe, North America and South America (FAO 1957). Common carp was then the most popular species, followed by the Mozambique tilapia (*Oreochromis mossambicus*). In Malaysia the snakeskin gouramy (*Trichogaster pectoralis*) was favored, and Nile tilapia (*Oreochromis niloticus*) was used in Egypt. Other species mentioned include buffalo fish (*Ictiobus cyprinellus*), the Carassius[4] (*Carassius*

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[3] Wet rice cultivation includes the IRRI rice ecosystems of rainfed lowland, flood-prone and irrigated rice that together make up 87% of the world's rice area and 96% of the rice production (IRRI 2001).

[4] Note that older reports mention the term “goldfish” only and Ardiwinata (1957) suggests that both *Cyprinus carpio* as well as *Carassius auratus* were included.

auratus), milkfish (*Chanos chanos*), mullets (*Mugil* spp.), gobies (family Gobiidae), eels, murrels or snakeheads (*Channa* spp.), catfish (*Clarias batrachus*), gouramy (*Trichogaster pectoralis*) as well as penaeid shrimps (*Penaeus* spp.).

Coche (1967) pointed out that in most countries rice-fish farming did not involve deliberate or selective stocking of fish and that the species cultured and the stocking density depended on what came in with the flood waters. Thus the species cultured usually reflected what was living in the waters used to flood or irrigate the rice fields. It appears that rice-fish farming did not spread out from one focal point but may have developed independently.

3. The Rice Field Ecosystem

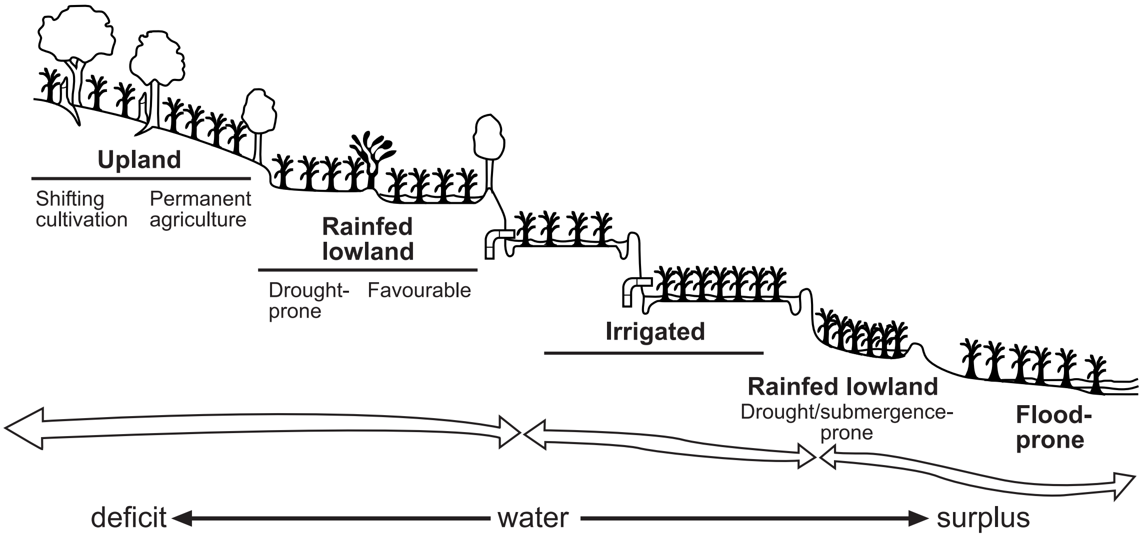
3.1 Types of Riceland Ecosystem

Rice farming is practiced in several agro-ecological zones (AEZs) although most of the rice farming occurs in warm/cool humid subtropics (AEZ 7), warm humid tropics (AEZ 3) and in warm sub-humid tropics (AEZ 2). Cutting across the AEZs, IRRI (1993) has categorized rice land ecosystems into four types: irrigated rice ecosystem, rainfed lowland rice ecosystem, upland rice ecosystem, and flood-prone rice ecosystem (Figure 1). Apart from the upland system, the others are characterized by wet rice cultivation. Asia accounts for over 90% of the world's production of rice and almost 90% of the world's rice land areas. In the irrigated rice ecosystem, the rice fields have assured water supply for one or more crops a year. Irrigated lands cover over half of the world's rice lands and produce about 75% of the world's rice supply.

The rainfed lowland rice ecosystem is characterized by its lack of control over the water and by both flooding and drought problems. About one quarter of the world's rice lands are rainfed.

The upland rice ecosystem varies from low-lying valleys to undulating and steep sloping lands with high runoff and lateral water movement. The soils vary in texture, water holding capacity and nutrient status since these could range from the badly leached alfisols of West Africa to fertile volcanic soils in Southeast Asia. Less than 13% of the world's rice land is upland rice.

The remaining rice lands are classified as flood-prone rice ecosystems (almost 8%), subject to uncontrolled flooding, submerged for as long as five months at a time with water depth from 0.5 to 4.0 m or more, and even intermittent flooding with brackish water caused by tidal fluctuations. Included here are tidal rice lands in coastal plains.



Upland	Rainfed lowland	Irrigated	Flood-prone
Level to steeply sloping fields; rarely flooded, aerobic soil; rice direct seeded on plowed dry soil or dibbled in wet, non-puddled soil	Level to slightly sloping, bunded fields; non-continuous flooding of variable depth and duration; submergence not exceeding 50 cm for more than 10 consecutive days; rice transplanted in puddle soil or direct seeded on puddle or plowed dry soil; alternating aerobic to anaerobic soil of variable frequency and duration	Leveled, bunded fields with water control; rice transplanted or direct seeded in puddle soil; shallow flooded with anaerobic soil during crop growth	Level to slightly sloping or depressed fields; more than 10 consecutive days of medium to very deep flooding (50 to more than 300 cm) during crop growth; rice transplanted in puddle soil or direct seeded on plowed dry soil; aerobic or anaerobic soil; soil salinity or toxicity in tidal areas

Figure 1. Rice land ecosystems (after Greenland 1997 as adapted from IRRI 1993).

Flooding is not the only problem in these areas as they may also suffer from drought as well as acid-sulphate and/or saline soils.

Regardless of the ecosystem, fish can conceivably be raised wherever wet rice cultivation is practiced. The main determinant in the feasibility of raising fish in any given rice land is the availability of water and the water holding or dike-forming characteristic of the soil. The volume and seasonality of water dictate the fish-culture approach for any given area. Rice lands where the water supply is highly seasonal or constrained have limited options for rice-fish farming, whereas year-round supply of water provides greater potential for rice-fish culture. Reference to rice lands and rice fields in the rest of this document refers to wet rice cultivation.

3.2 The Wet Rice Field Ecosystem

The wet rice field can be described as a “temporary aquatic environment” (Roger 1996) or “a special type of wetland” that can be considered “a successor of shallow marshes or swamps” (Ali 1998), which is influenced and maintained by farmers’ activities. Heckman (1979) suggested that as long as the land was farmed it would maintain its equilibrium from year to year.

In general, the aquatic environment in rice fields is characterized by shallowness, great variation in turbidity as well as extensive fluctuations in temperature, pH and dissolved oxygen. Owing to the intermittent nature of the standing water, the aquatic flora and fauna, which may be rich, are transitory in nature and must have their origins in the irrigation canals and water reservoirs (Fernando 1993).

This section is not meant to be exhaustive but focuses on subjects that are relevant to the raising of fish in rice fields. For a more comprehensive discussion on the rice field ecosystem, the reader is directed to Heckman (1979) or Roger (1996). The focus here is on the main aspects of the rice field ecosystem that affect the animals and plants living in the rice field as well as a brief overview of the inhabitants themselves.

3.2.1. Factors affecting fish and other aquatic organisms

The main factors affecting the fish and other animals in the rice field are the water level, temperature, dissolved oxygen (DO), acidity (measured as pH) and unionized ammonia (NH_3). Other factors are also important but not to the same extent. For a more detailed discussion on how various factors affect fish and other aquatic organisms, the reader is advised to consult Boyd (1979, 1982).

The water level in rice fields often varies from 2.5 to 15.0 cm depending on the availability of water and the type of water management followed, making it an unsuitable environment for organisms requiring deeper waters. This is the first and often major constraint to the types of organisms that may be able to live in the rice field environment. This is naturally not the case in flood-prone rice lands.

With such shallow depth, the water is greatly affected by weather conditions (solar radiation, wind velocity, air temperature and rainfall). In addition, a flooded rice field functions like a greenhouse, where the layer of water acts like the glass of a greenhouse. Short-wave radiation (light) from the sun heats up the water column and the underlying soil, but long wave radiation (heat) is blocked from escaping, thus raising the temperature. Figure 2 shows the amount of heat that can accumulate is dependent on many factors, but usually makes the water and soil temperature in a rice field higher than the air temperature (Roger 1996).

Maximum temperature measured at the soil/water interface can reach 36-40°C during mid-afternoon, sometimes exceeding 40°C during the beginning of the crop cycle. Diurnal fluctuations are often about 5°C and decrease with increased density of the rice canopy. Maximum diurnal variations of over 16°C have been recorded in Australia.

As all animals consume oxygen the amount of DO is of great importance, although some organisms are amphibious and others can use atmospheric oxygen. The DO concentration in a rice field is the result of mechanical, biological and chemical processes. The mechanical processes consist of wind action and the resultant diffusion through the air-water interface. A major source of DO in the water column is the photosynthetic activity of the aquatic plant biomass that can lead to super-saturation in the mid-afternoon, although at night the oxygen is used up by the respiration by plants. Thus, together with respiration by animals, bacteria and oxidation processes, anoxic conditions result during the

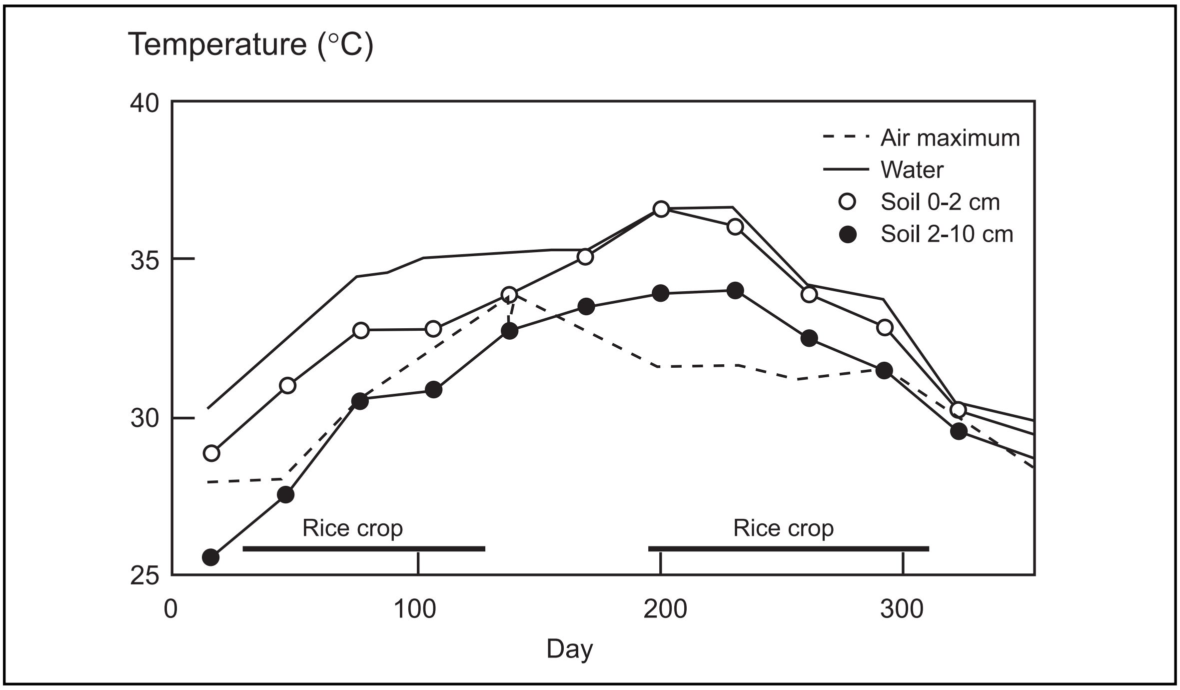


Figure 2. Average monthly values of maximum air temperature and of temperature in the flood water, upper (0-2 cm) and lower (2-10 cm) soil at 1400 hr, IRRI farm, 1987 (Roger 1996).

night and pre-dawn period (Fernando 1996). This is more pronounced in deepwater rice fields, which can become anoxic during the second half of the rainy season (University of Durham 1987).

Respiration uses oxygen and produces carbon dioxide (CO_2) that when dissolved in water forms carbonic acid (H_2CO_3), which in turn dissociates into bicarbonates (HCO_3^-) and carbonates (CO_3^{-2}). This results in the release of hydrogen ions (H^+) which increase the acidity of the water, and cause the pH to drop. Atmospheric CO_2 through natural diffusion and agitation on the surface water and decomposition of organic matter are other important sources of carbon dioxide. On the other hand, removal of CO_2 from the water due to photosynthetic activity causes the hydroxyl ions (OH^-) to increase and raises the pH of the water.

The DO level and pH of the water in a rice field are positively correlated since the DO concentration is largely a result of photosynthetic activity that uses up carbon and reduces the dissolved CO_2 (and thus H^+ concentration), effectively raising both pH and the DO levels. Conversely both are lowered during the time when respiration dominates (Figure 3). Depending on the alkalinity (or buffering capacity) of the water, these diurnal variations can range from zero DO to super-saturation and from acid to highly basic (pH>9.5) waters during times of algal blooms (Roger 1996).

Ammonia (NH_3) is an important source of nitrogen in the rice field. In its ionized form, NH_4^+, ammonia is rather harmless to fish, while its unionized form, NH_3, is highly toxic. The proportion of the different forms is dependent on the pH of the water, where the NH_3 concentration increases by a factor of 10 per unit increase of pH between pH 7 to 9 (Roger 1996). As such the ammonia concentration in the water can cause the death of fish and other organisms when the pH of the water reaches high levels, particularly so after applying nitrogen-rich fertilizer to the rice fields.

3.2.2. Factors affecting plants

The main factors affecting the plants in the rice fields are water, light, temperature, soil nutrients (nitrogen, phosphorus, potassium and other minerals) as well as the farming practices. The rice field flora consists of the rice plants as well as many types of algae and other vascular macrophytes. The vegetation apart from the rice plants is often referred to as the photosynthetic aquatic biomass (PAB). The algae alone in a rice field have been reported to develop a biomass of several tonnes fresh weight per hectare (Roger 1996).

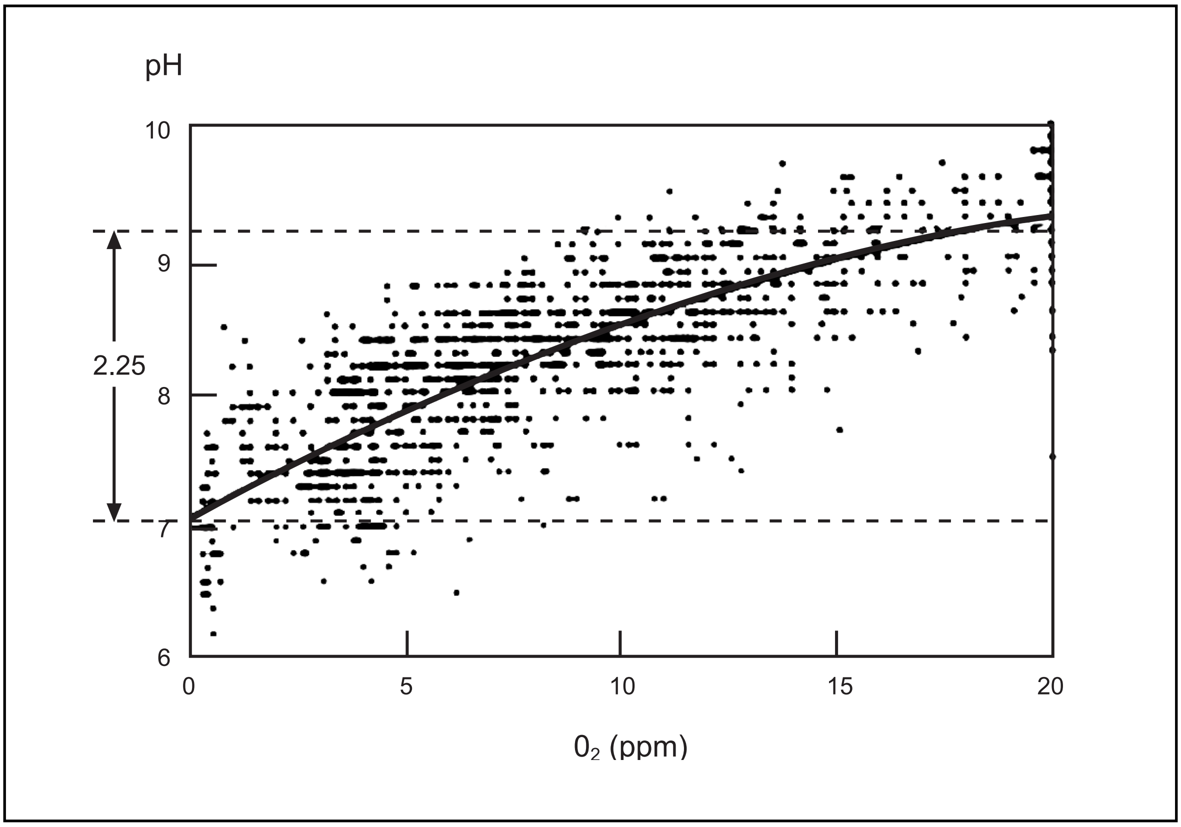


Figure 3. Correlation between the Oxygen concentration of the flood water and pH in five flooded soils (P.A. Roger and P.M. Reddy, IRRI 1996 unpublished from Roger 1996).

A continuous flooding of 5.0-7.5 cm water is considered best for optimum grain yield, nutrient supply and weed control. When the rice starts to ripen, the plants need very little water and usually the rice fields are drained about 10 days before harvest to make the work easier. Drying the rice field results in a drastic shift in the composition of floral species as only soil algae and spore-forming blue-green algae (cyanobacteria) can withstand periods of dryness. The chemical make-up of the water in rice fields depends initially on its source (rainfall, flood water from a river, an irrigation canal or a well). Once it becomes part of the rice field, its composition changes drastically due to dilution by rain, dispersion of the surface soil particles, biological activity and most of all fertilizer application.

The amount of sunlight in a rice field depends on the season, latitude, cloud cover, as well as the density of the plant canopy. The crop canopy causes a rapid decrease in the sunlight reaching the water. One month after transplanting, the amount of light reaching the water surface may drop by as much as 85% and after two months by 95% (Figure 4). Shading by the rice plant can limit the photosynthetic activities of algae in the rice field as the rice crop grows. Turbidity of the flood water, density of plankton, and floating macrophytes further impair light penetration. Light availability influences not only the quantity but also the species composition of photosynthetic aquatic biomass. Many green algae are adapted to high light conditions while the blue-greens or cyanobacteria are regarded as low light species. Certain species of blue-green algae are, however, known to be resistant to or even favored by high light intensity (Roger 1996).

Both high and low temperatures can depress phytoplankton productivity and photosynthesis. Similar to sunlight, the temperature may also have a species-selective effect. Higher temperatures favor the blue-greens while lower temperatures stimulate the eukaryotic algae.

Soil factors also determine the composition of algae where acid soil favors chlorophytes (green algae) and alkaline soil fosters nitrogen-fixing cyanobacteria. Application of agricultural lime ($CaCO_3$) in acidic soil increases the available nitrogen and promotes growth of cyanobacteria. High amounts of phosphorus also seem to be a decisive factor for the growth of the blue-green algae.

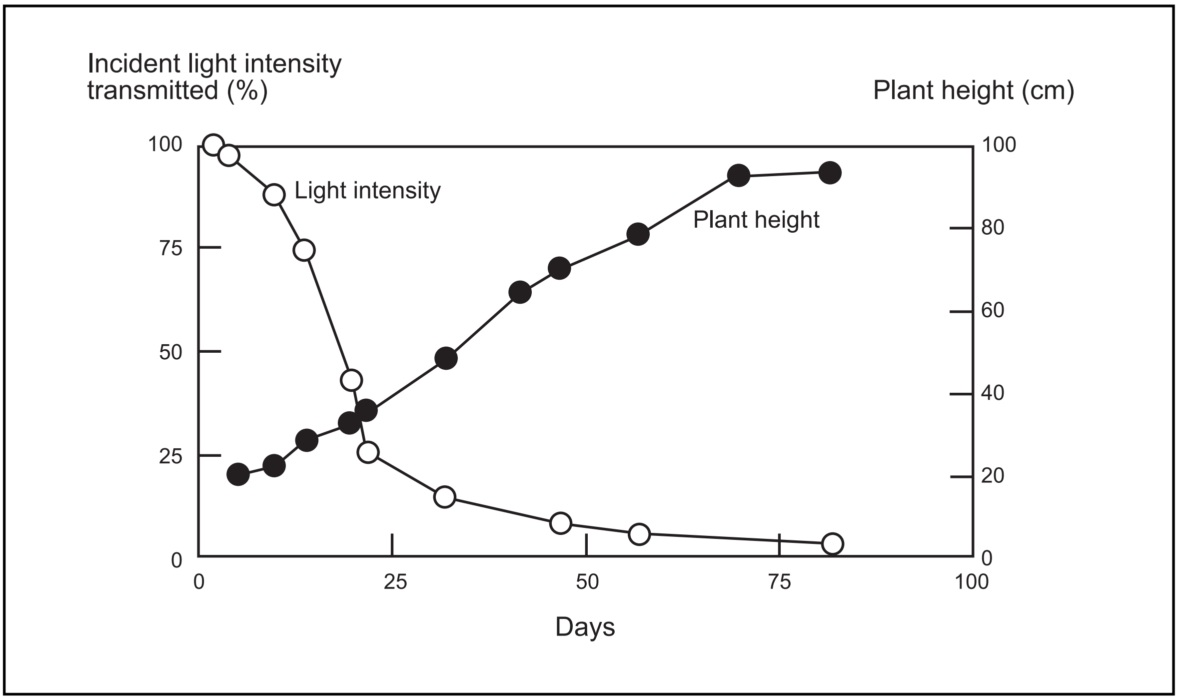


Figure 4. Relation between plant height and incident light intensity transmitted under the new canopy (Kurasawa 1956 from Roger 1996).

The most profound effects on the rice field flora may be those resulting from human intervention or farming practices. Tillage results in the incorporation of algae and macrophytes and their spores into the soil and dispersion of clay particles in the water. After being mixed with the soil, it is likely that the motile forms of algae such as flagellates will be more successful at re-colonisation since these are capable of moving to the surface to be exposed to sunlight. The suspension of clay particles, on the other hand, makes the water turbid and results in reduced amount of light available for photosynthesis. Mineralized nitrogen is released rapidly into the flood water following land preparation. This is believed to be the reason behind algal blooms frequently observed immediately after puddling.

The method of planting also affects algal growth. Transplanting favors algal growth compared to broadcasting since broadcasting results in an earlier continuous canopy which curtails light compared to transplanting.

Fertilization, while intended for the rice plant, cannot but affect the growth and development of all the aquatic organisms in the flood water. The effects depend on the type of fertilizers and micronutrients used and may vary from site to site. Moreover, each plant and algal species also react differently to separate applications of N, P, K and $CaCO_3$.

Of importance to rice-fish culture is the application of nitrogen rich fertilizer such as ammonium sulphate $[(NH_4)_2SO_4]$ and urea. Application results in an increase of ammonia concentration in the water, up to 40-50 ppm with ammonium sulphate and less than half of that with urea. Phosphorus application, which is often done at monthly intervals, stimulates algal growth and thus productivity. Otherwise it has no effect on the animals in the rice field.

Surface application of NPK frequently results in profuse algal growth with the planktonic forms developing first followed by the filamentous forms that persist longer. Nitrogen-rich fertilizer favors growth of eukaryotic algae while inhibiting the growth of blue greens. In phosphorus-deficient soils, the addition of phosphorus fertilizers or phosphorus-rich manure enhances the growth of algae. Calcium is rarely a limiting factor to algal growth in rice fields, but liming stimulates the growth of blue-greens by raising the pH. The use of organic manure may temporarily reduce algal growth during the active decomposition stage, but may later favor the growth of blue-green algae.

The composition of aquatic plants in a rice field may also be determined by the organisms in the field, which may be pathogens, antagonists or grazers. Certain bacteria, fungi and viruses are pathogenic and influence succession. Some algae are antagonistic by releasing substances that inhibit growth. Finally, there are the animal grazers - organisms that rely on the aquatic plants as food, such as cladocerans, copepods, ostracods, mosquito larvae, snails and other invertebrates.

In the experimental rice plots of IRRI in the Philippines, primary productivity has been measured to range from 1.0 to 2.0 g $C \cdot m^{-2} \cdot day^{-1}$, but in most cases would range from 0.2 to 1.0 g $C \cdot m^{-2} \cdot day^{-1}$. These values are similar to the productivity values reported in eutrophic lakes.

3.2.3. Rice field fauna

The rice field has a surprisingly great biodiversity, perhaps the greatest of any tropical rainfed system, where Heckman (1979) recorded a total of 589 species of organisms in a rice field in Thailand. Of these, as many as 233 were invertebrates (excluding protozoans) representing six phyla of which over half were arthropod species. In addition, there were 18 fish species and 10 species of reptiles and amphibians. A similar number of fish, snails, crabs and larger insects are reported in Cambodia (Gregory and Guttman 1996).

Rice fields also serve as the habitat for birds and wildlife for part or all of their life cycle. Ali (1998) lists at least 13 bird species and 6 small mammals that may be found in rice fields.

The rice field biodiversity is under threat not only due to changing farming practices with widespread mechanization and use of chemical inputs, but also environmental degradation leading to the disappearance of permanent reservoirs (or refuges) for organisms within the vicinity of the rice fields (Fernando et al. 1979). Rice fields used to be, and remain, a rich source of edible organisms in many areas. Heckman (1979) found that one vegetable and 16 animal species were collected in a single rice field in Thailand. Similar figures are found in other areas of Southeast Asia (Gregory 1996; Gregory and Guttman 1996). Balzer et al. (2002) reported about 90 aquatic species (excluding plants) that are collected by Cambodian farmers in their rice fields and used daily by rural households. Such diversity of food from a rice field, while still common in many areas, is reported to be decreasing (Halwart 2003b).

3.2.4. Impact of aquatic fauna on the rice field ecosystem

The aquatic fauna plays an important role in nutrient recycling. Whether as primary or secondary consumers, animals excrete inorganic and organic forms of nitrogen and phosphorus and are a major factor in the exchange of nutrients between soil and water. Among the organisms, the benthic oligochaetes (family Tubificidae) have received special attention because they can move between the reduced soil (which lies beneath the shallow oxidized layer) and the flood water. Together with ostracods and dipteran larvae, oligochaetes respond positively to nitrogen fertilizer if applied by broadcasting, but not when applied by deep placement. Indigenous snail populations on the other hand are strongly affected negatively by broadcast application of N fertilizer (Simpson 1994).

Fish plays an important role in the nutrient cycle of the rice field ecosystem. Cagauan (1995) lists four ways how fish may influence the nutrient composition of the flood water and the oxidized surface soil as well as the growth of the rice plant. First, by contributing more nutrients to the rice field through faeces excretion as well as through decomposition of dead fish. Second, by the release of fixed nutrients from soil to water when the fish swims about and disperses soil particles when disturbing the soil-water interface. Third, by making the soil more porous when fish disturb the soil-water interface, fish increase the nutrient uptake by rice. Finally, fish assist in the recycling of nutrients when they graze on the photosynthetic biomass and other components of the ecosystem.

More specifically, fish affect the nitrogen cycle in a rice field. Cagauan et al. (1993) found that a rice field with fish has a higher capacity to produce and capture nitrogen than one without fish (Table 1). At the same time, fish may help conserve nitrogen by reducing photosynthetic activity (by grazing on the photosynthetic aquatic biomass and by increasing turbidity) and thus keeping the pH lower and reducing volatilization of ammonia. This may be important as nitrogen losses through ammonia volatilization have been estimated to be from 2 to 60% of the nitrogen applied (Fillery et al. 1984).

Fish also affect the phosphorus cycle. Phosphorus is often a limiting nutrient for primary production as it often becomes fixed in the soil and is unavailable to plants in the rice field. Fish, by disturbing the soil, increase soil porosity and promote phosphorus transfer to the soil. On the other hand, by grazing on the oligochaete population, fish may have exactly the opposite

Table 1. Summary statistics of N models of lowland irrigated rice fields with and without fish.

Unit	Rice	Rice-Fish
Total production (kg N/crop)	465.60	476.80
Total flow to detritus (kg N/ha/crop)	447.10	456.80
Total throughput (kg N/ha/crop)	1 122.22	1 183.60
Throughput cycled (kg N/ha/crop) (includes detritus)	334.40	346.30
Cycling index (%)	59.60	58.50
Mean path length	11.45	12.11

Source: Cagauan et al. (1993)

effect as oligochaetes also increase soil porosity. Plots without fish were found to have higher soil porosity because of the presence of undisturbed oligochaetes. Fish have been found capable of reducing oligochaete population in a rice field by 80% (Cagauan et al. 1993).

3.2.5. The rice field as a fish culture system

In principle, as long as there is enough water in a rice field, it can serve as a fish culturing system. However, a rice field is by design intended for rice and therefore conditions are not always optimum for fish. At the most basic level is the fact that rice does not necessarily need standing water at all times to survive. Rice can be successfully grown in saturated soils with no standing water (Singh et al. 1980), and recent evidence on the system of rice intensification suggests that intermittent irrigation may increase rice yields. However, even with a continuously standing column of water, a flooded rice field is not necessarily an ideal place for growing fish. The water temperature can reach very high levels. Also, rice requires fertilizer which increases the total ammonia level in the water and can thus increase the highly toxic (to fish) un-ionized ammonia level in the water. Rice does not require oxygen in the water - an element essential for most fish. Finally, rice farming requires other human interventions which may be detrimental to the survival and/or growth of fish, such as mechanical weeding or herbicide application. Some of the contrasting requirements of rice and fish are summarized in Table 2.

Table 2. Comparison between environmental requirements of fish and rice.

PARAMETER	NORMAL RANGE	
	RICE	FISH
1. Depth of Water	Minimum: saturated soils with no flooding; Ideal: Continuous flooding starting at 3 cm depth gradually increasing to max of 15 cm by 60th day. Complete draining 1 – 2 weeks before harvest (Singh et al. 1980).	0.4-1.5 m for nursery and 0.8-3.0 m for grow-out (Pillay 1990)
2. Temperature	Water and soil temperature of up 40°C and fluctuations of up to 10°C in one day apparently with no deleterious effect.	25°-35°C for warmwater species. Stable temperature preferable. Feeding may slow down at temperatures below or above normal range. Metabolic rate doubles with every 10°C rise.
3. pH of water	Neutral to alkaline.	6.5-9.0 (Boyd 1979).
4. Oxygen	Important during seedling stage for development of radicles.	Preferably at near-saturation or saturation level (5.0-7.5 ppm depending on temperature).
5. Ammonia	High levels of ammonia common immediately after fertilization.	Un-ionized ammonia highly toxic. Ionized form generally safe.
6. Transparency or Turbidity	Immaterial.	Important for growth of natural food. Very high level of suspended soil particles may impair respiration.
7. Culture Period	90-120 days for HYV; up to 160 days for traditional varieties.	120-240 days depending upon species and market requirement.

4. Modification of Rice Fields for Fish Culture

Several physical modifications have been devised over the years in order to make the rice field better suited for fish culture. Most are common to many countries and may have been developed independently from each other as a result of a "common sense" approach that characterizes many traditional practices.

All modifications have the basic goals of providing deeper areas for the fish to grow without inundating the rice plants and of limiting escape from and access to the rice field. This is achieved either by making portions of the rice field deeper than the ground level for the fish, or conversely, by creating areas higher than the ground level for the rice or other crops. There are four physical improvements that are commonly made to prepare rice fields for fish culture. The first is to increase the height of the dike or bund to allow deeper water inside the field and/or to minimize the risk of it being flooded. The second is the provision of weirs or screens to prevent the fish from escaping as well as keeping predatory fish from coming in with the irrigation water. The third, which is not always practiced but often recommended, is provision of proper drains and finally, provision of deeper areas as a refuge for the fish. Details of the various modifications have been described by various authors (e.g. FAO et al. 2001) and this section will provide a complementary overview.

4.1 Increasing Dike (Bund) Height

Rice field embankments are typically low and narrow since the usual rice varieties do not require deep water. To make the rice field more suitable for fish, the height of the embankment needs in most cases to be increased. Reports on rice-fish culture from various countries show embankments with a height of 40-50 cm (measured from ground level to crown). Since the water level for rice does not normally exceed 20 cm, such embankments will already have a freeboard of 20-30 cm. This is sufficient to prevent most fish from jumping over. The height of the embankments cannot of course be increased without a corresponding increase in the width. There are no hard and fast rules as to the final width, but generally it is within the range of 40-50 cm.

4.2 Provisions of Weirs or Screens

Once the fish are inside the rice field, efforts are made to prevent them from escaping with the water, regardless of whether it is flowing in or out. To prevent loss of the fish stock, farmers install screens or weirs across the path of the water flow. The screens used depend on the local materials available. FAO et al. (2001) list three types of screens: bamboo slats, a basket, and a piece of fish net material (even a well-perforated piece of sheet metal).

4.3 Provision of Drains

In general rice fields are not equipped with gates for management of water levels. The common practice is to temporarily breach a portion of the embankment to let the water in or out at whatever point is most convenient. This is understandable since typically dikes are no more than 25-30 cm high with an almost equal width. Using a shovel, a hoe or bare hands, water can be made to flow in or out. Repairing the dike afterwards is just as easy.

The larger dike required for rice-fish culture makes it more difficult to breach, and it will also take more effort to repair. It is therefore advisable to provide a more permanent way of conveying water in or out just like in a regular fishpond, although this may incur an extra cost. Generally reports do not contain enough detail on the type of water outlets installed, but among these are bamboo tubes, hollowed out logs, metal pipes or bamboo chutes (FAO et al. 2001; IIRR et al. 2001).

4.4 Fish Refuges

A fish refuge is a deeper area provided for the fish within a rice field. This can be in the form of a trench or several trenches, a pond or even just a sump or a pit. The purpose of the refuge is to provide a place for the fish in case water in the field dries up or is not deep enough. It also serves to facilitate fish harvest at the end of the rice season, or to contain fish for further culture whilst the rice is harvested (Halwart 1998). In conjunction with the refuge, provisions are often made to provide the fish with better access to the rice field for feeding.

There are various forms of refuges ranging from depressions in a part of the rice field, to trenches to a pond adjacent to the field connected with a canal. A multitude of systems have been reported, but they all follow the same principles. This section will provide a brief overview of the various types of refuges that are practiced in rice-fish culture, divided into trenches, ponds and pits or sumps. It should be noted that it is not uncommon to combine trenches with ponds or pits, and also that these designations are rather imprecise as it is a gradual change from a trench to a lateral pond and likewise from a pit to a pond and a rather academic issue, of limited practical value, to determine when a trench becomes a lateral pond and vice versa.

4.4.1 Trenches

Before describing the various ways trenches have been used in rice-fish culture, it is worthwhile to note that trenches can have three functions: as a refuge should water levels drop, a passageway providing fish with better access for feeding in the rice field and as a catch basin during harvest (De la Cruz 1980).

There are several ways the trenches could be dug. The simplest way involves just digging a central trench longitudinally in the field. Figure 5 illustrates the great variations on this rather simple theme (Koesoemadinata and Costa-Pierce 1992).

Xu (1995a) reported on the practice to dig trenches in the shape of a cross and even a “double-cross”, a pair of parallel trenches intersecting with another pair, in larger rice fields (from 700 up to 3 000 m^2).

The trenches are just wide enough and deep enough to safely accommodate all fish during drying and weeding and usually require only the removal of two rows of rice seedlings. In this manner, the trenches do not significantly affect the production of the rice crop. Reported widths are approximately 40-50 cm (Koesoemadinata and Costa-Pierce 1992) and a suggested minimum depth is 50 cm, measured from the crown of the bund to the bottom of the trench resulting in the bottom of the trench being 25-30 cm to below the field level (Ardiwinata 1953). Sevilleja et al. (1992) reported a design with a 1 m wide central trench with water from a screened inlet flowing directly into it a narrow peripheral trench. Another experimental design in the Philippines used an ”L-trench” involving two sides of the rice field, with a width of 3.5 m occupying 30% of the rice field area.

For fingerling production, the ditches are dug together with 50-70 cm deep 1 m^2 pits or sumps at the water inlet and outlets. Rice seedlings are planted along both sides of each ditch and three sides of each pit to serve as “a fence” (Wan et al. 1995).

A variation, reported from China, is a “wide ditch”[5] measuring 1 m wide and 1 m deep, placed laterally along the water inlet side of the rice field with a ridge rising about 25 cm above the field level. It is constructed along the side of the ditch that is away from the embankment. To allow the fish to forage among the rice plants, 24 cm-wide openings are made along the ridge at 3-5 m intervals. These ditches occupy around 5-10% of the rice field area.

Having a small number of trenches limits the area for raising fish. To provide more area for them, farmers sometimes dig shallow trenches (also referred to as furrows or ditches) using the excavated soil to form ridges where rice is transplanted. In this manner trenches and ridges alternate with one another throughout the whole rice field (Figure 6; Li 1992). The dimensions of the ridges and ditches are not hard and fast, varying from one place to another. Ridges range from 60 to 110 cm to accommodate 2 to 5 rice seedlings across (Li 1992; Ni and Wang 1995; Xu 1995a). Ditches range from 35 cm wide by 30 cm deep to 50 cm wide and 67 cm deep (Li 1992; Xu 1995a; Xu 1995b; Ni and Wang 1995). One or two ditches may be dug across all the ridges to connect them and improve the water flow. During transplanting water is only in the trenches. Afterwards the fields are filled up to the top of the ridge. Although this method can improve low-yielding rice fields since it makes multiple use of available resources (Ni and Wang 1995), Wan and Zhang (1995) noted the limited adaptability of this approach since the method requires a lot of work that must be repeated each year. Extension efforts in Jiangxi Province, China,

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[5] The words “trench” and “ditch”’ are synonymous here since the two words are used interchangeably in the literature on rice-field fish culture.

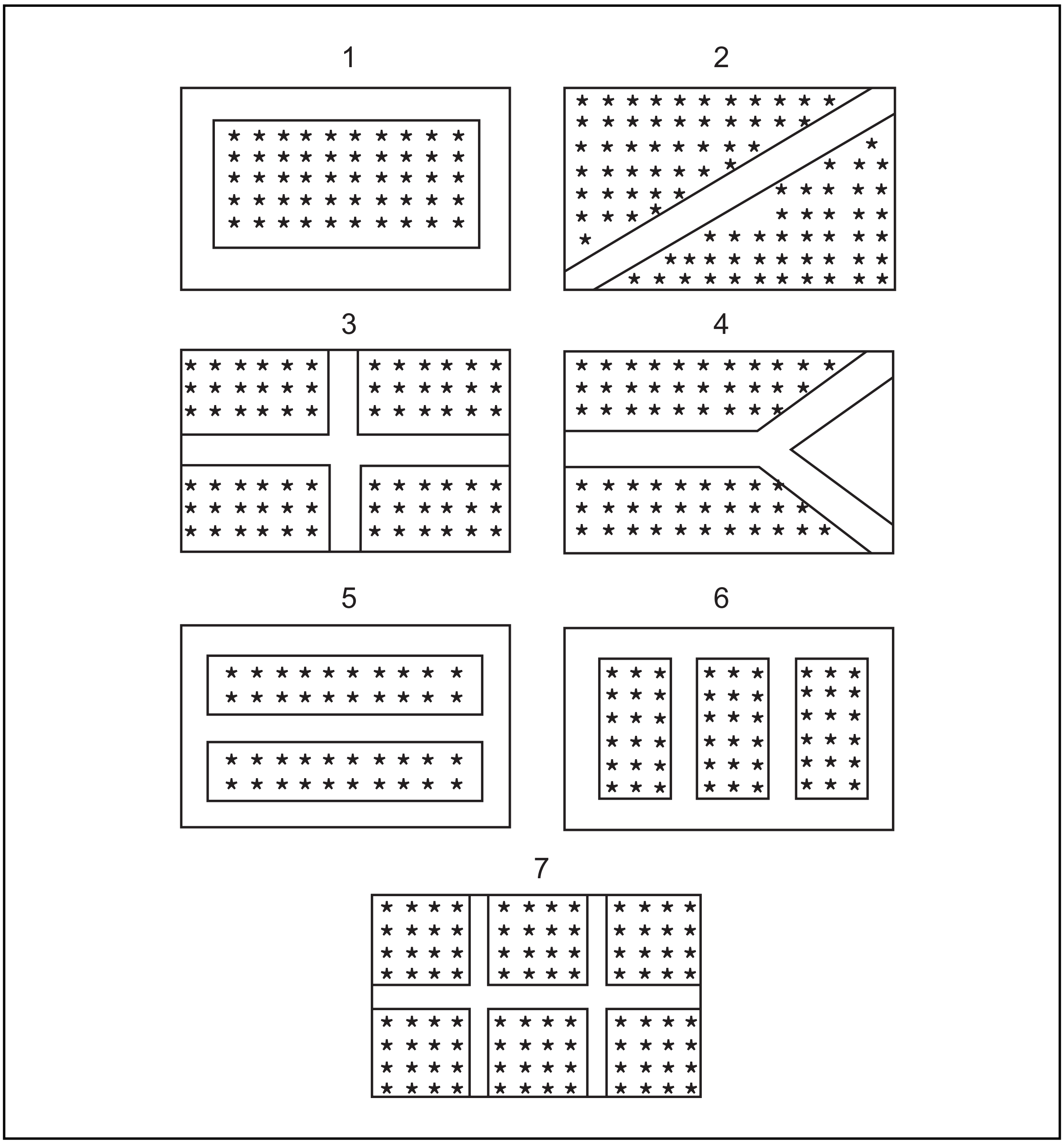

Figure 5. Design and construction of fish trenches in Indonesian rice+fish farms or minapadi (Koesoemadinata and Costa-Pierce 1992). 1– peripheral trench; 2 – diagonal trench; 3 – crossed trenches; 4 – Y-shaped trench; 5 – peripheral with one central longitudinal trench; 6 – peripheral with two equidistant transverse trenches; 7 – latticed trenches.

have been successful in establishing this model in 0.5% of the rice-fish farming area.

By utilizing the dikes of the rice fields to cultivate dryland crops the field can be described as a multi-level system. One such system is the *surjan* system (Figure 7) found in coastal areas with poor drainage in West Java, Indonesia. The dikes are raised to function as beds for dryland crops. The trenches, the rice area and the dikes form three levels for the fish, rice and dryland crops (Koesoemadinata and Costa-Pierce 1992).

Xu (1995a) described a development resulting in a seven-layer rice-fish production system practiced in Chongqing City, China. The seven “layers” were: sugarcane on the ridges, rice in the fields, wild rice between the rows of rice, water chestnuts or water hyacinth on the water surface, silver carp in the upper layer of the water column, grass carp in the middle layer, and common carp or crucian carp at the bottom. In order to utilize rice fields comprehensively for better economic, ecological and social benefits, many experiments on multi level systems have been set up such as

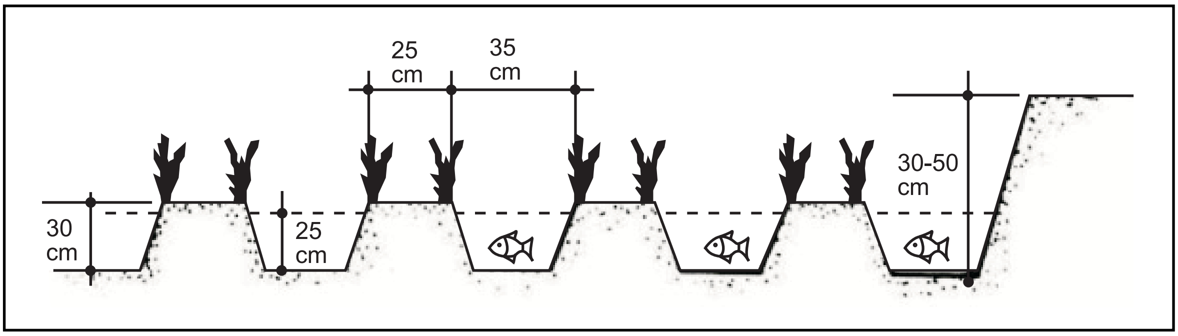

Figure 6. Rice ridge and fish ditch farming system in China (Li Kangmin 1992).

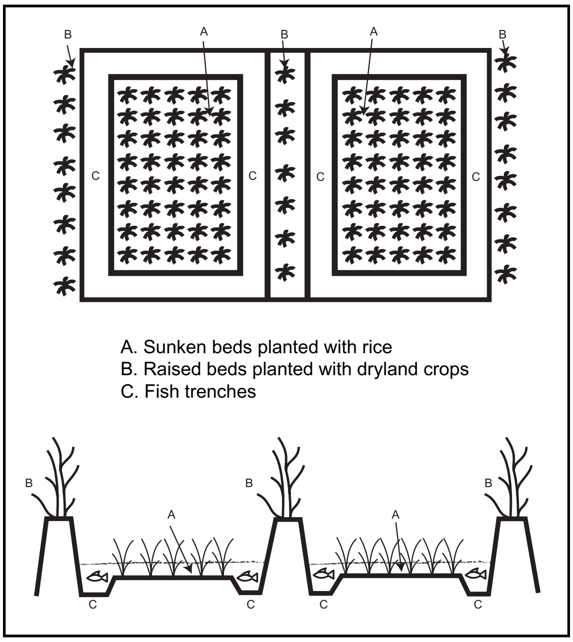

Figure 7. Design of Indonesian rice-fish-vegetable farm or surjan (Koesoemadinata and Costa-Pierce 1992).

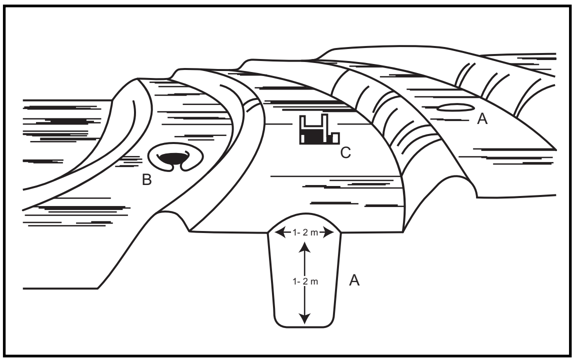

Figure 8. Cross-section of Ifugao rice terraces in the Philippines showing traditional fish harvesting pits (Ramsey 1983).

rice-crab-shrimp-fish in Jiangsu Province, rice-fish-mushroom in Helongjiang Province, rice-fish-animal husbandry-melon-fruit-vegetables in Guizhou Province, and rice-lotus-button crab in Beijing (Li Kangmin, pers. comm.).

4.4.2 Fish pits or sumps

In some countries sumps are provided as the only refuge without any trench, for example when traditional beliefs do not allow major modifications of rice fields as in the rice terraces of the Philippines (Halwart 1998). Coche (1967) found that farmers in Madagascar dig one sump for every 100 m^2, each measuring 1 m in diameter and around 60 cm deep. A “stalling pond” was also provided to hold fingerlings.

Sumps can serve as a catch basin during harvest in addition to providing refuge for the fish. Figure 8 illustrates sumps of 1-2 m width and depth dug in the center of the rice field for this purpose (Ramsey 1983). Sumps may just be simple excavations but modifications exist such as sumps lined with wooden boards to prevent erosion or a secondary dike built around them (Ramsey 1983). In Bangladesh, farmers excavate a sump occupying 1-5% of rice field area with a depth of 0.5-0.8 m (Gupta et al. 1998).

4.4.3 Ponds in rice fields

Another approach to provide a relatively deeper refuge for fish in a rice field is the provision of a pond at one side of the rice field. There is no clear-cut boundary as to when a “trench” becomes wide enough to be considered a pond.

In Indonesia the *payaman* or lateral pond (Figure 9) is used in rice fields that are located right beside a river. The pond is constructed here so that water from the river has to pass through the pond to get into the rice planting area. A dike separates the pond from the rice planting area. Openings are made along the dike to enable the water to flow freely to the rice and allow the fish to forage within the rice field. When the rice field is drained, the pond serves as a refuge for the fish, making it possible to catch them after the rice harvest. According to Koesoemadinata and Costa-

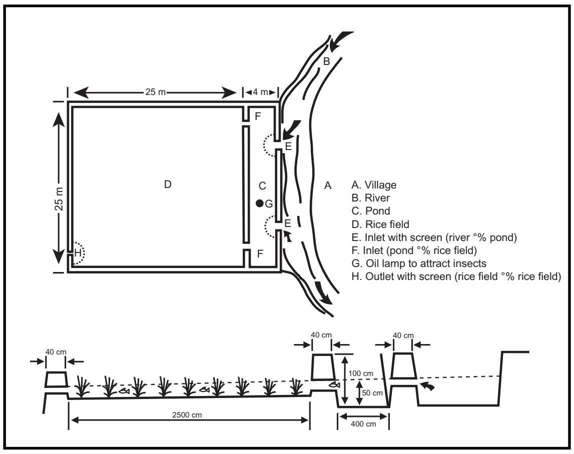

Figure 9. Design and construction of Indonesian rice+fish farm with lateral pond or *payaman* (Koesoemadinata and Costa-Pierce 1992).

Pierce (1992) it is a way of making "better use of an unproductive part of a rice field."

A Philippine rice-fish model involves the provision of a minimum of 500 m^2 fishpond in any one-hectare rice field. In India, instead of providing a pond only at one end of the rice field, the West Bengal State Fisheries Department introduced a design involving two ponds, one at each end of the rice field (Figure 10). The ponds have a top width of 18 m and pond bottom width of 1.5 m. They are 1.5 m deep measured from the field level. The rice field has a total length of 125 m (inclusive of 3 m dikes). Thus the ponds actually cover 28% of the gross rice field area and the dikes about 4.8%. Even with such a large area devoted to fish, farmers in the area who used the deepwater pond system reportedly were still able to realize an annual harvest of 5.1-6.4 mt of rice per ha (Ghosh 1992).

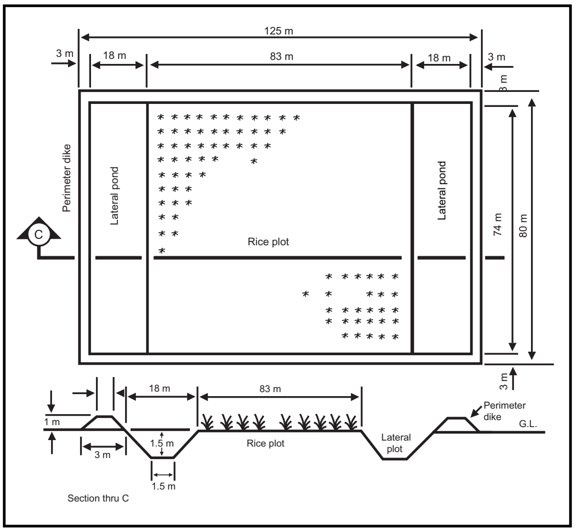

Figure 10. Typical rice-fish pond in West Bengal State Fisheries Department, India (Ghosh 1992).

The lateral pond design is the most popular form of rice field modification in Jiangxi Province, China (Wan et al. 1995). A small pond is dug at one end of the field, or shallow pond(s) between the rice fields can be made. The ponds are 1 m deep and occupy only 6-8% of the total field area. The ponds are supplemented by 30-50 cm deep ditches that cover about one-third of the total pond area.

With the lateral pond, farmers have the option of making temporary breaches along the partition dike separating the pond from the rice field to interconnect the fishpond with the rice field, therefore allowing the fish to graze among the rice plants. Water for irrigating the rice has to pass through the fishpond. By draining the rice field and repairing the breach, the fish are made to congregate in the pond compartment and their culture continues independent of the agronomic cycle of the rice. Thus the fish, if still under-sized, can be cultured through the succeeding rice crop if necessary. This model makes it possible to take advantage of the mutualism between rice and fish while desynchronizing the fish culture cycle from that of rice.

Another option is to maintain a deepwater fishpond centrally located in the rice field as is reported from hilly areas in Southern China. In Sichuan province, where per caput fish production is low and rice-fish farming is perceived as a promising way of increasing it, circular ponds made of bricks and cement are placed in the middle of the rice fields (Halwart, pers. comm.). Ghosh (1992) reported on a 1.5 m deep pond in India that measured 58 x 58 m in the center of a 1 ha rice field (Figure 11). Note that in the figure the fishpond deceptively looks much larger than the rice area when in fact it occupies exactly one-third of the total area.

4.4.4 Rice fields in ponds

The *sawah-tambak* rice field - fish pond combination (Figure 12) – in Indonesia is unique to the low-lying (1-2 m above sea-level) coastal areas of East Java. These areas are flooded throughout the wet season but lack water during the dry season. Farmers construct 1.4-2.0 m high dikes around their land with a 3 m wide peripheral trench parallel to the dike. A second dike is built around the rice field that is low enough to be flooded over (Koesoemadinata and Costa-Pierce 1992).

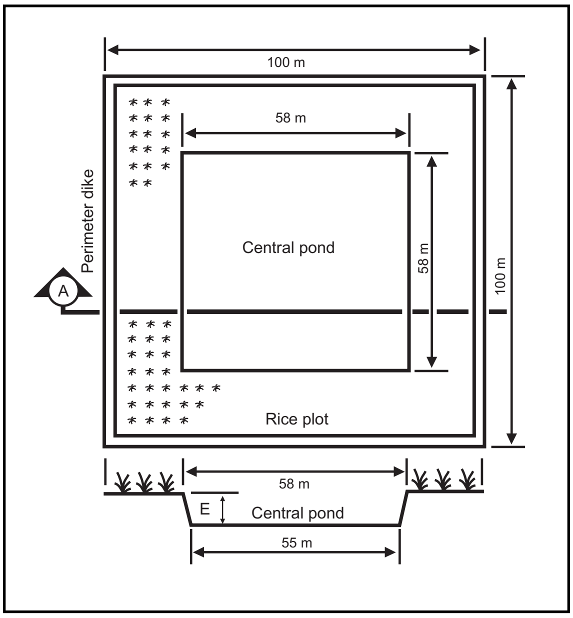

Figure 11. Central fishpond within a rice field in India (Ghosh 1992).

Milkfish (*Chanos chanos*) and silver barb (*Barbodes gonionotus*) are the main species raised in the polyculture system, although the common carp and the giant freshwater prawn (*Macrobrachium rosenbergii*) may be grown together with both species. These are adaptable for either concurrent or rotational systems of rice-fish culture.

4.4.5 Ponds connected to rice fields

In the most important rice-fish farming area in peninsular Malaysia (northwestern Perak), the practice is to dig a small pond at the lowest portion of the land, separate from the rice field, which is connected with the rice field through the inlet/outlet gate (Ali 1992). The pond is typically no more than 6-8 m in length and width and has a depth of 2 m. Fish can graze in the rice field and still seek refuge in the sump pond when the water in the rice field is low or too hot. When the rice is harvested, the pond is drained and the fish harvested as well. Small fish are left behind to provide stock for the next season.

This type of system was also reported from China (Ni and Wang 1995) with a 1.5 m deep pond that was used for fry production. Fish are concentrated in the pond only during harvest time. Once the subsequent rice crop is planted and established, the fish are allowed to graze freely again.

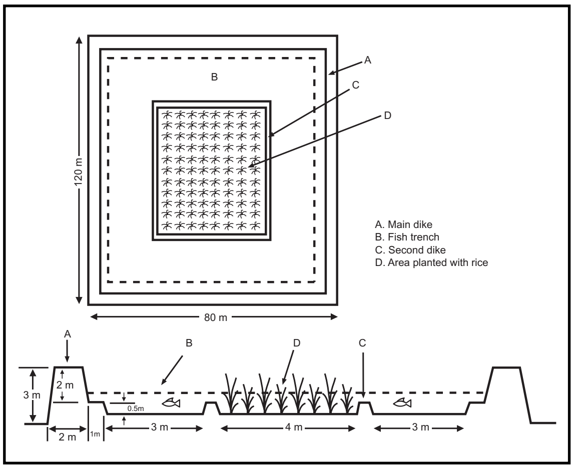

Figure 12. Design and construction of Indonesian coastal rice+fish farm or *sawah-tambak* (Koesoemadinata and Costa-Pierce 1992).

A similar system was promoted in Cambodia (Guttman 1999) by connecting small ponds dug for households under a “food for work” scheme with the adjacent rice fields. The fish were often kept in ponds until the Khmer New Year (mid-April) as the fish prices were at a peak then.

4.4.6 Fish pen within a rice field

Farmers in Thailand set enclosures within the natural depressions of a rice field to grow fry to 7 cm fingerlings for direct stocking into the rice fields. The enclosures are made of plastic screens or - less prevalently - bamboo fencing. Fish are stocked in these enclosures after the first rains when the water has reached 30-50 cm. Owing to the turbidity during this period, plankton productivity is low and the fish have to be fed. Farmers try to reduce the turbidity by surrounding these depressions with a low dike. For added protection from predators, the net pen material is embedded in the dike (Sollows et al. 1986; Chapman 1992; Fedoruk et al. 1992; Thongpan 1992; Tokrishna 1995; Little et al. 1996).

A net pen can be a useful option in deepwater rice fields where flood waters over 50 cm might persist for four months or longer. This has been tried in Bangladesh using a 4 m high enclosure (Gupta 1998). However, investment costs of the net enclosures to contain the fish have often made the operation uneconomical and unsustainable.

5. Production Systems

In categorizing the production systems, it is not possible to completely divorce the purely physical design aspects from the cropping practices. This is because a particular cropping practice may require some specific physical modifications although the converse may not be true. A particular modification does not necessarily limit the cropping practice to be employed. Farmers can always sell their fish as fingerlings if they find it financially advantageous to do so, or conversely grow them to larger size as table fish. Farmers in many areas routinely switch between, or cycle through, rotational and concurrent practices using the same rice field.

This section will describe the two main production systems, concurrent culture – growing the fish together with the rice in the same area - and rotational culture – where the rice and fish are grown at different times. The final part will mention an alternating system that is really a type of rotational culture, but distinct enough to warrant a separate section.

5.1 Concurrent Culture

The growing of fish simultaneously with rice is what comes to mind for most people when rice-fish culture is mentioned. This is often referred in short as “rice+fish” (Yunus et al. 1992; Roger 1996). As mentioned earlier, physical modifications are required to make a rice field “fish-friendly”. The timing in stocking fingerlings is crucial since if stocked too soon after the rice is planted, some fish species are likely to damage the newly planted seedlings (Singh et al. 1980), and if too late there may be a multitude of predator species in the fields.

It should be mentioned that the earliest and still most widely practiced system involves the uncontrolled entry of fish and other aquatic organisms into the rice field. Coche (1967) called this method the “captural system of rice-fish culture.” This can only be considered a rice-fish culture system if the fish are prevented from leaving once they have entered the rice field. In this system, the organisms often depend wholly on what feed is available naturally in the field, although it is not uncommon for farmers to provide some type of supplementary feeds. This system is often practiced in rainfed areas and plays an important role in many rice-producing countries, for example in Thailand where rainfed areas constitute 86% of the country’s rice area (Halwart 1998), as well as in the Lao PDR (Funge-Smith 1999) and Cambodia (Guttman 1999; Balzer et al. 2002). The transition from a pure capture system and a capture-based culture system is gradual and has been described as a continuum (Halwart 2003b).

5.1.1 Rice and fish

The stocking and growing of fish in a rice field is basically an extensive aquaculture system that mainly relies on the natural food in the field. On-farm resources and cheap, readily available feedstuff are often provided as supplementary feeds, particularly during the early part of the growing cycle. For the management of the rice crop, compromises are made with respect to the application of fertilizer, which is done judiciously. The use of pesticides is minimized and when applied the water level may be lowered to allow the fish to concentrate in the refuge.

One constraint of the concurrent system is that the growing period of the fish is limited to that of rice, which is usually 100 to 150 days. Consequently the harvested fish are small, especially if early-yielding rice varieties are used. This can be partly remedied by the use of larger fingerlings, but there is a limit to this since large fish may be able to dislodge the rice seedlings. Another solution is to limit the production to that of large-size fingerlings for sale to farms growing table fish. The increased demand for fingerlings for growout in cages during the late 1970s in Indonesia was one of the catalysts that helped popularize rice-fish farming.

This system is practiced widely although there are many variations of the basic theme. For example, in the *minapadi* - literally “fish-rice” system - of Indonesia, the rearing of fish is not one continuous process. It consists of three distinct rearing periods that are synchronized with the rice cultivation. Two different explanations have been given for such a procedure: not to subject the fish to very turbid conditions (Ardiwinata 1957) and not to adversely affect rice yields (Koesoemadinata and Costa-Pierce 1992). The first period takes place from 21 to 28 days between rice transplanting and first weeding; the second period during the 40 to 45 days between the first and second weeding; and the third, during the 50 days between the second weeding and the flowering of the rice plants.

The first and second rearing periods may be considered the nursery periods for growing the fry to fingerling size. The rice field is stocked at the rate of 60 000 fry $\cdot$ ha^{-1}. During the first weeding, the fish stock is confined to the trenches. Before the second weeding, the fingerlings are harvested and sold. In the third growing period, 8-10 cm fingerlings are stocked at the rate of 1 000 to 2 000 fish $\cdot$ ha^{-1} for the production of food fish.

To have more food available for the fish, the Chinese have introduced the growing of azolla together with the fish and rice. Aside from serving as food for the fish, azolla is also a good nitrogen source for the rice because of its nitrogen-fixing capability (Liu 1995). This system works well in either fields with pits or with rice on the ridges: azolla on the surface of the water and fish within the water column (Yang et al. 1995). The field must have sufficient water and good irrigation and drainage. The proportion of pits and ditch as to the total area depends on the desired yields of rice and fish.

Yang et al. (1995) found that both fish and rice yields varied according to the ridge width or ditch width. Fish yields also vary according to the species cultured and the stage at which they are harvested (Wang et al. 1995). The output of fish was highest using “food fish” followed by carp fry, catfish fry (*Clarias gariepinus*), and the lowest yield with grass carp. Chen et al. (1995) reported a 70% increase in fish yield with azolla over culture without azolla.[6]

5.1.2 Rice and fish with livestock

Carrying the concept of integration one step further, livestock rearing may also be integrated with rice-fish systems. This has been tried in many areas but is not as common as the integration of livestock with pond culture.

The most common form of integration is probably the rice-fish-duck farming. The integration of one hundred laying ducks with a one ha rice-fish farm resulted in the production of 17 031 eggs/year in addition to the rice and fish (Syamsiah et al. 1992). It should be noted that ducks are also known to feed on snails, and this combination of biological control agents has been suggested for controlling the various life stages of golden apple snails in rice fields (Halwart 1994a; FAO 1998).

5.1.3 Rice and crustaceans

Crustaceans raised in rice fields range from crabs and crawfish to prawns and shrimp.[7] This is being practiced in many coastal areas relying either on natural recruitment or in stocked fields.

In the southern United States, crawfish (*Procambarus clarkii*) are stocked in their adult stage to serve as broodstock unlike most other aquaculture systems where juveniles are stocked. Reproduction occurs in the rice field and it is the offspring that are harvested. The broodstock are released in the month of June after the rice has reached 10-25 cm and the rice field is already flooded. While the rice is growing, the crawfish reproduce and grow. By August the rice is ready for harvesting. Two weeks before harvesting, the rice field is drained to make harvesting easier. By this time all the crawfish are expected to have completed their burrowing (NAS 1976).

The rice stubble left after harvesting re-grows as a ratoon crop when the field is re-flooded and the new growth is foraged directly by the crawfish (Chien 1978). Loose plant material decomposes and serves as food for zooplankton, insects, worms and molluscs, that make up a large part of the crawfish diet. Although any type of vegetation can serve as forage for crawfish, rice appears to be more widely used. When the field is re-flooded after the rice harvest, the young crawfish are flushed out of their burrows and partial/selective harvesting can start as early as December and proceed through April/May to June/July depending upon the desired cropping pattern. Crawfish are harvested at 15-60 g size by using traps made of plastic or wire screens with ¾ inch mesh and baited with gizzard shad or carp. Lanes between the stands of rice are provided to allow the harvesting boats to move freely.

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[6] The system used “fine feed” to feed pigs that produce manure for the rice fields and “beer left-overs” as supplementary feed.

[7] The term “prawn” is used for freshwater species and “shrimp” for marine and brackishwater organisms.

Although the river crab or mitten-handed crab (*Eriocheir sinensis*) has been cultured with rice in China for less than 12 years, there are now almost 100 000 ha devoted to its culture[8] (Wang and Song 1999). The rice field is used either as a nursery for the production of crab juveniles (or "button-crab"); growout for the production of marketable-sized crabs (125 g); or as a fattening area for rearing undersized crabs (50-100 g).

The rice field is modified with a peripheral trench (2-4 m wide, 1 m deep), a cross trench (0.8-1.0 m wide, 0.5-0.8 m deep) and a sump (20-60 m^2, 1 m deep) as a nursery-rearing-harvesting "pond". In total 15% to 20% of the total area is modified. To prevent crabs from escaping, a wall of smooth material (plastic or corrugated sheet) is installed (Li 1998).

While saltwater is needed for egg hatching and rearing the larvae at the initial stage, at later stages the larvae can develop into crabs in a freshwater or near-freshwater environment. Li (1998) identified the stage stocked in rice fields as zoea that in four months attain "stage V zoea" at 40 to 200 individuals per kg. Wang and Song (1999) found megalopa[9] stocked needed to be slowly acclimated (six to seven days) to near freshwater condition (below 3 ppt) for better survival when stocked in freshwater. It is at this stage that they are either reared into button-crabs or reared directly into adults. For the production of button-crabs, the rice fields are stocked at the rate of 4.5-7.6 $kg \cdot ha^{-1}$. For growing into marketable crabs, the stocking rate is 75-150 $kg \cdot ha^{-1}$. These are harvested upon reaching the size of 125 g.

Supplementary feed is given consisting of a mix of trash fish, snail, clam or viscera of animals (40%); vegetables, sweet potatoes, pumpkin, rice or wheat bran, leguminous cakes (25%); and terrestrial grass or duck weeds (35%). The trash fish and other animal protein source are steamed and minced finely during the early stage of growth. The vegetable materials are stewed and are given during the middle stage. At the late stage animal feeds are again given in order to fatten the crabs and develop the gonads that make the crabs even more prized. Pellet feeds are also used in some places.

Good water management is essential and about 20 cm of the water is changed every three days or one-third of the water of the entire field every 10 to 15 days. The dissolved oxygen level is maintained at a level above 4 ppm throughout the culture period. Basal manuring and top-dressing with urea are applied two to three times a year.

The rice crop is harvested at "frost's descent" and the crabs by October and November when the gonads are ripe. The time of harvest may be advanced if the temperature should abruptly drop since the crabs have a tendency to burrow when the temperature is low. The crabs are concentrated in trenches by irrigating and draining prior to the rice harvest. The crabs are caught when they crawl out of the trenches at night by using bottom trap nets or by draining the water.

The giant freshwater prawn (*Macrobrachium rosenbergii*), as well as another prawn species (*M. nipponensis*), grow together with rice in China. The physical preparations are the same as for river crabs in terms of providing trenches, sumps and screens; so are pre-stocking preparations up to the liming stage (Li 1988). Thereafter, submerged aquatic plants are planted in the trenches to cover one-half to one-third of the water surface.

For *M. rosenbergii*, the stocking rate is 3 pieces · per m^2 of 1.5 cm sized juveniles.[10] The *M. nipponensis* on the other hand may be stocked as 4-6 cm size brooders at 3.0-3.8 $kg \cdot ha^{-1}$ and allowed to breed, or as juveniles at 23-30 pieces · per m^2. The feed consists of soybean milk and fish gruel for the early stages (seven to eight days after stocking the fry) and pelleted feeds or a mixed diet of wheat bran or rice bran and some animal protein source thereafter. The *M. rosenbergii* is fed a higher protein diet.

M. rosenbergii is harvested before the temperature drops too low. Harvest for *M. nipponensis* can start on a selective basis by late November or early December. The undersized animals are left to grow for the total harvest by May or June before the rice planting season.

In coastal rice fields encroached by saltwater, it is common for saltwater shrimps to enter the rice fields with the floodwater and grow among the rice plants. In the Mekong Delta area in Vietnam

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[8] This includes pens and cages set in lakes, ponds, and rice fields.

[9] Megalopa is the last larval stage of crabs before they metamorphose into fully-formed juvenile crabs. It is the most likely the more accurate designation of the crab larvae when stocked in the rice fields.

[10] This rather low stocking rate is due to the aggressive behavior of the prawn.

some farmers have been successful in growing shrimp together with a traditional tall rice crop in a brackishwater environment. Supplementary feeding results in higher yields even when the feed consists of nothing more than "rice bran, broken rice and rotten animals" (Mai et al. 1992).

5.1.4 Concurrent but compartmentalized culture

Rice culture and fish culture both require water and in some circumstances the rice and fish are cultured side by side sharing the water. One advantage of this set-up is that fish rearing becomes independent from rice, making it possible to optimize the conditions for both rice and fish. However, the synergistic effect of rice and fish on each other is no longer present. Generally there is only a one-way influence from fish to rice in the form of nutrient-enriched water.

In the rice culture zone of Senegal, environmental changes have forced the rice farmers to diversify and integrate fish culture in their farming operations (Diallo 1998). Owing to two decades of drought, the foreshore mangrove areas have expanded resulting in the salinization of surface and ground water. To protect their rice fields against the inflow of saltwater, farmers built fishponds along the foreshore area to produce fish. The fishponds range from 500 to 5 000 m^2 (30 cm deep with 1 m deep peripheral canal).

During the first rain, the gates of the rice fields and fishponds are opened to allow the rainwater to wash away any salt that may have accumulated. Then the gates are closed and the rainwater and surface runoff are collected for both the rice planting and fish growing operations. After the rice has been planted from mid-August to mid-September, the seaward gates are opened during the spring tides. Coastal fish attracted by the flow of freshwater come into the ponds and are trapped. No attempt is made to control the species and the number of fish that enter. The rice fields and fishponds are fertilized with cattle and pig manure and ash. The fish are fed rice bran, millet bran and sometimes termites.

The fish are harvested either when the rice is about to mature or just after the rice has been harvested from December to January, when the fish have been growing from 120 to 150 days. Harvesting is done during low tide by draining the pond with a basket locally known in Senegal as *etolum* placed at the end of the drainpipe.

5.2 Rotational Culture

5.2.1 Fish as a second crop

In Hubei and Fujian provinces, China, raising fish during the fallow period or as a winter crop is practiced to make use of the rice field when it otherwise would not be used (Ni and Wang 1995). Elsewhere in China it does not seem to be as widely practiced as concurrent culture. In Indonesia, particularly West Java, the art of rotating fish with rice has been developed to a greater degree and can be traced back to 1862 or earlier.

The Indonesians call raising fish as a second crop *palawija* or "fallow-season crop." Instead of growing another rice crop or soybeans or maize after one rice crop, some Indonesian farmers grow fish. The only physical modification required is the raising of the dike to hold water. Without the rice, the entire rice field can be operated and managed just like a regular fishpond from three to six months a year. It can be used for growing table fish or producing fingerlings. The production of two or three crops of fingerlings instead of one crop of table fish is done by some farmers in Indonesia to avoid problems of poaching or fish mortality due to infestation by predators such as snakes, birds and water insects (Koesomadinata and Costa-Pierce 1992).

Raising fish, in this case common carp as *palawija*, was described in detail by Ardiniwata (1957). The rice field is flooded with the rice stubble, either trodden down or cut off and stacked together with loose rice-straw, before or after the first flooding. Within two or three days the water becomes putrid due to the decomposition of plant materials and is released and replaced with new water. Water depth is maintained between 30-80 cm.

Carp fingerlings are stocked at a density that is based on the magnitude of the rice harvest and the size of the fingerlings. The rule of thumb is to stock from 500 to 700 fingerlings (5-8 cm long) for one tonne of *padi* (unhusked rice) harvested. Sometimes large fingerlings (100 g) are also stocked at the rate of 10% of the main stock. These larger fish keep the soil surface loose by their activities. Alternatively, 10-day old carp fry may be stocked at the rate of 100 000 fry · ha^{-1} for growing into fingerlings. This practice often results in high mortality but is apparently resorted to only if no other area is available as a nursery.

Marketable fish are harvested in 40 to 60 days, fingerlings after only 4 weeks. There is enough time for a second, third or even fourth crop of fish prior to the next rice planting season, depending on the availability of water. The stocking density is increased by 25% during the second fish cycle but then reduced since there is a risk of running out of water before the fish have reached marketable size. In Indonesia, a short growing period is possible since the local preference is for small fish averaging 125-200 g (Costa-Pierce 1992). Table fish are harvested by draining the field, forcing the fish into trenches where they are picked by hand. The field is left to dry for two days, repairs made and rice straw turned over and the field is ready once again for another crop of fish. To harvest fingerlings, a temporary drainpipe covered with a fine meshed screen is installed and then the water level is carefully lowered until it is only in the trenches. Fingerlings left in puddles on the trench floor are gathered first, and when only a little water is left, the fingerlings concentrated at the screened outlet are carefully scooped out and placed in holding vessels for distribution.

Another Indonesian system is called *penyelang* or “intermediate crop” where farmers who double-crop rice with an adequate water supply year-round find it possible to raise fish in between the two rice crops. Since the seedbeds occupy only a very small portion of the rice field, the farmers can use the rest of the rice fields for growing fish during a period of 1-1½ months sufficient to produce fingerlings. Some farmers let fish breeders use their rice fields during this period (Koesoemadinata and Costa-Pierce 1992). The whole rice field can be operated as a fishpond and with the widespread use of the high-yielding varities (HYVs) that make possible four to five crops of rice in two years, the *penyelang* is reported to be more popular than the *palawija* described earlier.

The fields are stocked after they have been tilled and made ready for the next rice crop and are already clean and free from rice stubble (Ardiwinata 1957). This makes them suitable for rearing carp fry and are sought after by fish breeders. The same stocking density is used as in *palawija* (100 000 fry · ha^{-1}). Fingerlings are harvested after only one month. If used for growing marketable fish, the stocking is 1 000 fish · ha^{-1} (8-11 cm). As long as trenches are provided, whether peripheral or otherwise, the fish may remain during the plowing and harrowing process.

5.2.2 Crustaceans as a second crop

Along the western coast of India the low-lying coastal rice lands are left fallow after one crop of salt-tolerant rice (Pillay 1990). The dikes are raised after the rice is harvested (in September) and tidal water is allowed to inundate the field carrying with it shrimp larvae and fry. This natural stocking process continues for two to three months with every spring tide. Lamps are installed over the inlet to attract the shrimp larvae and conical bag nets installed at the sluice gates to prevent the trapped shrimps from getting out. Selective harvesting may start as early as December allowing of the earliest shrimps to enter. Regular harvesting thins the stock resulting in better growth rate for the remaining stock. With such uncontrolled stocking, several species are harvested but mainly of *Penaeus indicus*, *Macrobrachium rud*e and *Palaemon styliferus*.

This system of shrimp culture is an old practice in India, but lately due to the high value of shrimps farmers are devoting greater attention to managing the shrimp stock through better water management and fertilization. Many farmers now no longer leave the stocking to chance preferring instead to stock at a controlled density using hatchery-produced postlarvae, particularly of *P. monodon*.

5.3 Alternating Culture System

Another alternative is an alternating system since rice takes from 105 to 125 days to mature depending on the variety, but fish can be marketable as fingerlings in as short as 30 to 45 days. Fish therefore can also be a good “time-filler” crop. By alternating between rice-fish and fish-only farming, rice fields can be productive throughout the year and higher incomes can be realized. A farmer may practice two rice crops and then a fish-only crop, or two rice-fish crops followed by a fish-only crop, with the latter becoming more popular in parts of Indonesia (Koesoemadinata and Costa-Pierce 1992). Ironically enough, even if rice is the main crop, fish are raised year-round in the rice field rather than rice. In a survey in West Java, farmers who practiced two rice-fish crops followed by a fish-only system had a net return to input of 173% per year as against 127% for those practicing a rice-rice-fish system and 115% for those practicing rice-rice-fallow system (Yunus et al. 1992).

6. Agronomic and Aquaculture Management

As mentioned earlier rice and fish sometimes have conflicting requirements. Growing fish in the rice field does require some modifications to the management to ensure that the fish get their necessary requirements and to facilitate fish survival and growth during certain critical periods. This section focuses on the additional or modified management interventions that are needed for rice-fish culture.

6.1 Pre-Stocking Preparation

Whether the modification is in the form of trenches, lateral ponds or higher and wider dikes, nothing suggests that one form of modification can be considered superior to others. The type of modification used is based on a combination of different factors: the terrain, soil quality, water supply, traditions, exposure to other methods, past experiences, relative importance given to either rice and fish, whether fingerling or food fish is desired and the financial resources available. Although generally rice is the main crop in any rice-fish farming activity, there are exceptions where rice is planted or ratooned for the purpose of providing forage for the culture organism.

6.2 Water Needs and Management

Water is the most important single factor in any agricultural production. Merely supplying adequate water to enable a previously non-irrigated area to produce a dry season crop more than doubles the total annual production as rice production is often higher during the dry season than during the wet season. It is estimated that rice requires a minimum of 1 000 mm of water per crop, which is inclusive of both evapotranspiration and seepage and percolation (Singh et al. 1980). This is equal to 10 000 m^3 per hectare per crop.

Wet rice cultivation uses water either for a continuous submergence or intermittent irrigation. The latter has advantages, besides saving on water, but it may not be the best option for rice-fish culture since it requires concentrating the fish in trenches or sumps every time the rice field is dry. For rice-fish culture it is preferable to adopt continuous submergence where the rice field is kept flooded from the transplanting time to about two weeks before harvest.

Continuous flooding up to the maximum tolerated by rice without affecting its rice production is recommended. In most literature this is a standing water depth of from 15 to 20 cm (Singh et al. 1980; Rosario 1984; Koesoemadinata and Costa-Pierce 1992). At that depth, and with the fish refuge of whatever form having a depth of 50 cm below field level, the effective water depth of 65-70 cm is available to the fish in the refuge. This is sufficient to provide the fish with a cooler area when shallow water over the rice field warms up to as high as 40°C. The increased water depth means a greater volume of water for rice-fish farming. Despite the fact that seepage and percolation may be higher with deeper standing water, fish, unlike rice, do not consume water. Thus a farm with a rice-fish system operates similar to an extensive aquaculture system.

6.3 Fertilization

Application of fertilizers, organic or inorganic, benefits both rice and fish. The presence of adequate nutrients increases the growth of phytoplankton, which may be consumed directly by the fish or indirectly through supporting zooplankton production.

Early speculations indicated that rice-fish farming might use from 50% to 100% more fertilizers than rice farming without fish (Chen 1954) where the additional fertilizer was deemed necessary to support phytoplankton production as the base of the fish culture food chain. Recent reports indicate that the presence of fish in the rice field may actually boost rice field fertility and lower fertilizer needs.

Experiments in China indicate that the organic nitrogen, alkaline nitrogen and total nitrogen in the soil are consistently higher in fields with fish than in the control fields without fish (Wu 1995). Wu attributed this to the fact that fish in the rice field consume weeds and are able to assimilate 30% of the weed biomass. The rest is excreted that helps maintain soil fertility since nutrients, otherwise locked up in weeds, are released.

Further experiments showed that rice-fish plots require less fertilizer than rice-only plots. On average the control plots used 23% more fertilizer than the rice-fish plots (Li et al. 1995b). In summary, the Chinese experiments indicate that less, not more, fertilizer is required in rice-fish farming.

Fertilizer applied on rice-fish farms by incorporating the nitrogen fertilizer thoroughly in the soil during land preparation results in higher rice yields than when broadcast on the surface (Singh et al. 1980). Subsequent fertilization by applying urea as mudballs or as briquettes is a technique found to increase fertilizer efficiency by slowing down the release of the fertilizer. This avoids the problem of high ammonia concentration in the water, which may adversely affect fish growth. If the fertilizer is broadcast on the surface, the rice field should be drained to expose the planted area and confine the fish to the refuge trench or pond. Initial fertilization ought to be at the same level as in a rice-only farm since at this stage the fish are still small and cannot be expected to contribute significantly to the soil fertility. Less fertilizer should be needed in subsequent applications.

No difference has been found between applying the phosphorus fertilizer on the surface or incorporating it in the soil. However, surface application is believed to be better for promoting plankton growth in the water. Split applications of phosphorus may be better for sustained plankton production without hampering rice production as long as they are made before tillering. If applied at a later time, this should be on top of the normal requirements for rice. An application rate of 30-50 kg $P_2O_5 \cdot ha^{-1}$ is often reported as optimum for algal growth (Singh et al. 1980).

Organic fertilizers benefit both rice and fish. In addition to nutrients, the particles can also act as substrates for the growth of epiphytic fish food organisms. Animal manure should be considered an input to benefit the fish in addition to inorganic fertilizers applied primarily for the rice (Sevilleja et al. 1992). Manure should be applied several weeks before transplanting and the fields kept flooded for complete decomposition and to avoid any toxic effects (Singh et al. 1980).

Fertilization is a complex issue and varies greatly depending on the particular location. Providing general statements runs the risk of over-simplifying the issue, but there is evidence that nutrients are more efficiently utilized in rice-fish systems compared to rice-only systems, this effect being more enhanced particularly on poorer and unfertilized soils where the effect of fish may be greatest (Halwart 1998).

6.4 Rice Varieties

With the development of HYVs of rice, several issues affecting rice-fish culture have emerged. Among these are concerns about the unsuitability of short-stemmed varieties because of the deeper standing water required in rice-fish farming. This may be unfounded. Rosario (1984) listed varieties that have been successfully used for rice-fish farming that included one variety that has a tiller height of only 85 cm, and this concern may only apply to areas of moderate to deep flooding (≥ 50 cm).

The reduced growing period may be of greater concern, as many new varieties mature within approximately 100 days or less. With such a short culture period for fish there is a need to either stock large fingerlings, with the associated problems in fish dislodging and eating rice plants, or to harvest the fish early for further on-growing. The result is that this may make rice-fish farming a less attractive option in areas where large size fish are preferred. It should be noted here that in Southeast Asia small-sized fish are highly acceptable, particularly so in the Philippines and Indonesia.

6.5 The Fish Stock

6.5.1 Species

The fish to be stocked in rice fields should be capable of tolerating a harsh environment characterized by: shallow water, high (up to 40°C) and variable temperatures (range of 10°C in one day), low oxygen levels and high turbidity (Hora and Pillay 1962; Khoo and Tan 1980). Fast growth is also mentioned as a desirable characteristic so that the fish could attain marketable size when the rice is ready for harvest.

With such adverse environmental conditions that a fish could tolerate, it would seem that very few of the commercially valuable species are hardy enough to qualify. This, however, is not the case. A review of rice-fish farming practices around the world reveals that practically all the major freshwater species now being farmed, including a salmonid and even a few brackishwater species, have been successfully raised in a rice field ecosystem as well as several crustacean species (Table 3).

The species farmed in rice fields include 37 finfish species (from 16 families) and seven crustaceans (from four families). Molluscs, primarily snails and some clams are often harvested from rice fields, but there is little information that these are deliberately stocked.[11] The same is true with frogs and freshwater turtles.

Two groups of fish stand out in rice-fish farming: cyprinids and tilapias. The cyprinids, particularly the common carp and the Carassius have the longest documented history, having been described by early Chinese writers. The common carp has figured prominently since ancient times up to the present and is raised in rice fields in more countries than the other species. The grass carp and silver carp figure prominently, particularly in China, and the silver barb (*Barbodes gonionotus*) in Bangladesh, Indonesia, and Thailand, and the Indian major carps such as catla (*Catla catla*), mrigal (*Cirrhinus cirrosus*) and rohu (*Labeo rohita*) in Bangladesh and India.

The Mozambique tilapia (*O. mossambicus*) used to figure prominently in early literature, but is increasingly replaced by the Nile tilapia (*O. niloticus*) in many places. The Nile tilapia is now as widely used as the common carp in rice-fish farming.

Although rice-fish farming of the gouramis, specially *Trichogaster* spp., and climbing perch (*Anabas testudineus*) initially relied on natural stock, it is now cultured in Thailand using hatchery produced fry.

The crayfish (*Procambarus clarkii*) can also be considered a major species in rice field aquaculture since these are being raised in hundreds of thousands of hectares of rice fields in the American south. The practice is not widespread, mostly in the United States and to a limited extent in Spain (Halwart 1998).

Among the many species available for raising in rice fields, the choice is based on availability, marketability or desirability as food. In the Philippines, tilapia is the species of choice since carp does not have a wide market outside some small regional pockets. In Indonesia, people prefer common carp and silver barb over tilapia and these are therefore the species of choice for raising in rice fields. In China, people are more familiar with the various species of carp. With their long history of aquaculture, Chinese farmers are aware of the advantages of polyculture over monoculture so that polyculture of various species of carps seems to be the rule.

6.5.2 Fry and fingerling supply

The availability of seed[12] to stock the rice fields is in many areas a determining factor for the choice of culture species. It is also a critical part of any type of aquaculture development and is subject to the same factors as seed production targeted for pond and cage culture.

Hatchery and nursery technologies for most, if not all, of the freshwater fish species that are currently being cultured in rice-fish systems are well established. However, getting the required number of fingerlings of the desired species at a particular time remains a problem in many areas. This is especially acute in countries where mass production and distribution are still centralized in a government agency rather than in the hands of private producers. The issue of what is a suitable policy for the promotion of fish seed for aquaculture development is wide ranging and a thorough discussion is not possible in this report. Suffice it to say that general guidelines for the development of fish seed supply for aquaculture in general also hold true for rice-fish culture.

Some common problems associated with seed production and distribution are seed quality, genetics (broodstock quality), hatchery management and administration, transportation and stocking. It is best to involve as many people as possible in decentralized production and distribution of fish seed. Decentralization

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[11] Rice-clam (*Hyriopsis cumingii)* culture is practiced in Jiangsu Province, P.R. China. Farmers use rice fields as nursery for small pearl clams and then the small freshwater clams are hanged in ponds, pools, reservoirs or lakes. A rice-fish-frog model was tested in Jiangxi Province in early 1984. The experiment was conducted to control rice pests and diseases by frogs as well as fish. The farmed frogs included the black spotted frog *Rana nigromaculata, Rana plancyli, Rana tigrina rugulosa, Rana limnocharis, Microhyla butleri*, and the toad *Bufo bufo gargarizans* stocked at rates of 4950/ha and 9900/ha (Li Kangmin, pers. comm.)

[12] This term includes finfish fry and fingerlings as well as crustacean equivalents, such as post-larvae (PL), zooea or megalop.

Table 3. List of fish and crustacean species recorded as having been or being farmed in rice fields.

	Scientific Name	Common Name(s)	Countries Where Cultured
A. FINFISH			
Family Anabantidae	*Anabas testudineus*	Climbing perch	Malaysia, Thailand, Indonesia
Family Cichlidae	*Etroplus maculatus*	Orange chromide	India
	Etroplus suratensis	Pearl spot/Green chromide	India
	Oreochromis mossambicus		India, China, Taiwan, Zimbabwe, Sri Lanka, Malaysia, Thailand, Indonesia, Philippines
	Oreochromis niloticus	Nile tilapia	Egypt, Korea, Philippines, China, Bangladesh, Thailand, Cote d' Ivoire, Gabon, Tanzania
	Paratilapia polleni		Madagascar
	S. hornorum x S. niloticus	hybrid tilapia	Brazil
	Tilapia macrochir		Cote d' Ivoire
	Tilapia melanopleura		Pakistan
	Tilapia rendalli		Malawi
	Tilapia zillii		Egypt, Philippines
Family Cyprinidae	*Amblypharyngodon mola*		India
	Aristichthys nobilis	Bighead carp	China, Thailand, Taiwan
	Carassius auratus	Goldfish	China, Japan, Madagascar, Vietnam, Indonesia, Italy
	Catla catla	Catla	India, Bangladesh, Indonesia
	Cirrhina mrigala	Mrigal	India, Bangladesh, Indonesia
	Cirrhinus reba	Reba carp	Bangladesh
	Ctenopharyngodon idella	Grass carp	China, Bangladesh
	Cyprinus carpio	Common carp	China, India, Korea, Philippines, Indonesia, United States, Japan, Thailand, Vietnam, Madagascar, Brazil, Italy, Bangladesh, Hong Kong, Spain, Taiwan, Hungary, Pakistan
	Hypophthalmichthys molitrix	Silver carp	China, India, Korea, Philippines, Indonesia, Bangladesh
	Labeo bata		Bangladesh
	Labeo collaris		Vietnam
	Labeo rohita	Rohu	India, Bangladesh, Indonesia
	Mylopharyngodon piceus	Black carp	China
	Osteochilus hasseltii		Indonesia
	Puntius gonionotus	Minnow/Tawes	Vietnam, Thailand, Bangladesh, India
	Puntius javanicus (=Barbodes gonionotus)	Java carp/Silver barb	Indonesia, China
	Puntius pulchelus	Minnow	India
	Puntius sophore	Pool barb	India
	Puntius ticto	Ticto barb	India
	Rasbora danoconius	Slender rasbora	India
	Tinca tinca	Tench	Italy
Family Osphronemidae	*Osphronemus gouramy*		
	Trichogaster pectoralis	Snakeskin gourami	Malaysia, Pakistan, Indonesia
	Trichogaster sp.		Thailand
	Trichogaster trichopterus		Malaysia
Family Helostomatidae	*Helostoma temmincki*		Indonesia, Malaysia

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	Scientific Name	**Common Name(s)**	**Countries Where Cultured**
Family Anguillidae	*Anguilla japonica*		Japan, Taiwan, India
Family Channidae	*Channa striata (=Ophiocephalus striatus)*	Carnivorous snakehead	Malaysia, Thailand, India, Bangladesh
	Channa gachua		India
	Channa punctatus		India
	Chanos chanos		Philippines, Indonesia, India
	Ophicephalus maculatus		Vietnam, Taiwan
	Ophicephalus striatus	Snakehead	India, Malaysia, Indonesia, Philippines, Vietnam
Family Cobitidae	*Misgurnus anguillicaudatus*	Loach	Japan, Korea, Philippines
Family Centropomidae	*Lates calcarifer*	Seabass, baramundi	Australia, Thailand, Singapore, Philippines, Malaysia, Bangladesh, India, Myanmar, India, Vietnam, Kampuchea, Taiwan, China
Family Mugilidae	*L. parsia*	Gold-spot mullet	India
	L. tade	Tade mullet	India
	Liza sp.		India
	Mugil cephalus	Grey mullet	India
	Mugil corsula	Mullet	Bangladesh, India
	Mugil dussumieri		India
	Mugil parsia		India
	Mugil tarde		India
	Rhinomugil corsula	Corsula	India
Family Clariidae	*Clarias batrachus*		India, Thailand, Indonesia, Malaysia
	Clarias gariepinus		China
	Clarias macrocephalus	Omnivorous catfish	Malaysia
Family Pangasiidae	*Pangasius hypophthalmus*	Sutchi catfish	Cambodia
Family Ictaluridae	*Ictalarus lacustris*	Channel catfish	United States
	Ictalarus punctatus	Channel catfish	United States
Family Siluridae	*Parasilurus asotus*	Amur catfish	Korea, Vietnam
Family Atherinidae	*Atherina bonariensis*	Kingfish	Argentina
Family Curimatidae	*Prochilodus argentes*	Curimatá pacu	Brazil
	Leporinus elongatus		Brazil
	Prochilodus cearanesis		Brazil
Family Pimelodidae			
Other species:			
Family Heterpneustidae	*Heteropneustes fossilis*	Stinging catfish	India, Bangladesh
Family Pomacentridae	*C. dimidiatus*	Chocolatedip chromis	India
	C. ternatensis	Ternate chromis	India
	Chromis caeruleus	Green chromis	India
Family Mastacemblidae	*Macrognathus aculeatus*		India
	Mastacembelus armatus	Tiretrack eel	India
	Mastacembelus panealus	Barred spiny eel	India
Family Aplocheilidae	*Aplocheilus panchax*	Blue panchax	India
Family Nandidae	*Nandus nandus*	Gangetic leaffish	India
Family Notopteridae	*Notopterus notopterus*	Bronze featherback	India

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	Scientific Name	Common Name(s)	Countries Where Cultured
Family Ambassidae	*Ambassis nama*	Elongata glass-perchlet	India
	Ambassis ranga	Indian glassy fish	India
Family Gobiidae	*Glossogobius giuris*	Tank goby	India
	Pseudapocryptes lanceolatus		Vietnam
Family Catostomidae	*Ictiobus cyprinellus*	Bigmouth buffalo	United States
Family Centrarchidae	*Micropterus salmoides*		United States
Family Atherinidae	*Odontesthes bonariensis*	Silverside/Pejerrey	Argentina
Family Polynemidae	*Polydactylus sexfilis*	Sixfinger threadfin	Bangladesh
Family Bagridae	*Mystus gulio*	Tengra/Long whiskers catfish	India
	Mystus sp.		Bangladesh
Family Centrarchidae	*Lepomis* sp.		United States
Family Osphronemidae	*Osphronemus goramy*	Giant gourami	Malaysia
Family Plecoglossidae	*Plecoglossus altivelis*	Ayu fish	Japan
Other species:	*Beterotris niloticus*		Cote d' Ivoire
B. CRUSTACEANS			
Family Natantia	*Macrobrachium dayanum*		India
	Macrobrachium lamarrei		India
	Macrobrachium mirabile		India
	Macrobrachium niponensis		China
	Macrobrachium rosenbergii		Vietnam, Bangladesh, Brazil, India, Indonesia, China
	Macrobrachium rude		India
Family Penaeidae	*Penaeus indicus*		India, Vietnam
	Penaeus merguiensis		India
	Penaeus monodon		India, Bangladesh
	Penaeus semisulcatus		India
	Penaeus stylifera		India
Family Metapenaeidae	*Matepenaeus brevicornis*		India
	Metapenaeus ensis		Vietnam
	Metapenaeus lysianassa		Vietnam
	Metapenaeus tenuipes		Vietnam
	Metapenaues dobsonii		India
	Metapenaues monoceros		India
Family Astacura	*Procambarus clarkii*		United States, Japan
	Procambarus zonangulus		United States
Family Brachyura	*Eriocheir sinensis*	River crab	China
Other species:	*Palaemon styliferus*		India
	Parapenaeopsis sculptilis		India
	Acetes sp.		India

Note: Scientific names are listed as originally cited.

overcomes many problems of distribution and spreads the benefits of development more evenly. Special consideration should be given to the participation of women and disadvantaged groups such as landless families.

A fish seed network is a group of people producing and distributing fish seed in an informal but co-ordinated manner. As seed production and distribution develops, people involved in the network adopt more specialized roles. These networks are also important for information exchange. Most government hatcheries experience problems with seed distribution because they operate outside these informal networks. To maximize the opportunities for the poor, the following are recommended: promote small rather than large hatcheries; train people in the skills required for a range of network activities such as fry nursing, fingerling transportation, and hapa manufacturing; and organize micro-credit schemes to support people in fish seed networks.

6.5.3 Stocking pattern and density

Much like aquaculture using fishponds, rice-fish culture may involve the stocking of young fry for the production of fingerlings (nursery operation) or the growing of fingerlings into marketable fish (growout operation). Rice-fish farming may either be the culture of only one species (monoculture) or a combination of two or more species of fish and crustaceans (polyculture). Thus the stocking density varies depending on the type of culture as well as the number of species used. A final factor determining the stocking is the type of modifications to rice fields that has been made and what is considered the fish culture area. The variation is so great that it is difficult to provide even generalized guidelines, but Table 4 gives some information from several countries.

The stocking rate negatively affects the survival rate of fingerlings (for example, grass carp) and average body weight (ABW). At a density of 15 000 fingerlings · ha^{-1}, the survival rate was 3% higher than at 30 000 fingerlings · ha^{-1}, while the ABW was 11.4 g heavier than at 22 500 fingerlings · ha^{-1} and 20.6 g heavier than at 30 000 fingerlings · ha^{-1} (Yang et al. 1995).

Polyculture or stocking a combination of species makes it possible to take advantage of all the available food niches in the rice field ecosystem, aside from being able to manage a wider variety of pests. For example, a combination of common carp and grass carp has been found effective in controlling insects, snails and weeds because of the different feeding habits of the two species.

Table 4. Stocking densities for rearing fish in rice fields (Gupta et al. 1998; Li and Pan 1992; Sevilleja 1992;Quyen et al. 1992; Costa-Pierce 1992).

	Stocking Density (fish/ha)	
	Concurrent	**Rotational**
Monoculture		
Oreochromis niloticus	3 156 to 5 000	10 000
Cyprinus carpio	3 000 to 3 400	
Barbodes gonionotus	3 017	
Polyculture		
O. niloticus + *C. carpio*	3 000 + 2 000 3 070 total	(6 000 to 10 000) + (4 500 to 5 000)
C. carpio + *B. gonionotus*	4 667 total	
Multispecies (carp+barb+ tilapia)	9 323 total	
C. carpio + *C. auratus* + *C. idella*	(1 500 to 2 250) + (750 to 1 200) + (300 to 450)	
O. niloticus + *C. carpio* + *C. idella*	(6-10 cm: 6 000 to 9 000 or 3 cm: 12 000 to 18 000) + (300 to 600) + (150 to 300)	
B. gonionotus + *M. rosenbergii*	26 000 + (5 000 to 20 000)	
Fingerling production		
1-3 cm *C. carpio* (30 days)		70 000 – 100 000
3-5 cm *C. carpio* (50 days)		10 000 – 15 000
5-8 cm *C. carpio* (50 days0		6 000 – 10 000
5- 8 cm *C. carpio* (50-90 days)		1 500 –3 000
8-11 cm *C. carpio* (30 days)		1 000 – 2 000

Research indicates that although yield increases with higher stocking density (positive correlation), this should be compared with the increased mortality and associated increase in costs of stocking. A positive correlation has been found between fish production and stocking density (Gupta et al. 1998). At a mean stocking density level of 3 825 fingerlings per ha during the dry season and 2 948 per ha during the wet season in Bangladesh, the average production was 233 $kg \cdot ha^{-1}$ and 118 $kg \cdot ha^{-1}$ respectively. At stocking densities of more than 6 $000 \cdot ha^{-1}$ during the wet season the mean production reached 571 $kg \cdot ha^{-1}$. On the other hand, a negative correlation was found between the stocking density and recovery rate such that a 1% increase in the stocking density the survival rate decreased by 0.14% with an insignificant decrease in harvest size.

6.5.4 Fish nutrition and supplemental feeding

Fish graze and feed on a wide range of plant and animal organisms; preferences however vary between species as well as with the stage of development within species. For example, among cyprinids the common carp has the widest range in food and can feed on a variety of plant and animal matter. Another important factor is the presence and abundance of food organisms, for example it has been shown that juveniles of the rice-consuming aquatic snails *P. canaliculata* may become a major food item of common carp in rice fields (Halwart et al. 1998). Table 5 provides an overview of the diets of different species of tilapias (Bowen 1982).

The capability of *O. mossambicus* and *T. zillii* to consume weeds even in a pond or rice field situation has also been reported (Hauser and Lehman 1976), with *T. zillii* regarded as more superior as a natural “weedicide”. Although listed as a phytoplankton, feeder studies indicate that the Nile tilapia may prefer certain categories of algae such as filamentous cyanobacteria over diatoms and green algae (Micha et al. 1996). The species is not considered macrophytic but in a culture situation the Nile tilapia is known to feed on chopped terrestrial plants such as Napier grass and aquatic plants including water spinach *Ipomoea aquatica* as well as brans, cassava or termites.

The rice field ecosystem is rich in phytoplankton, zooplankton, macrophyton, benthos, detritus and bacteria. If the different types of natural food organisms available in a rice field ecosystem are fully exploited by stocking a proper combination of fish species, Li and Pan (1992) estimated that it can support up to a maximum of over 500 $kg \cdot ha^{-1}$ of fish as shown in Table 6. This estimate of the natural carrying capacity of a rice field as an aquaculture system is by no means a constant figure, as it will vary from place to place and from season to season. However, to produce more than the natural carrying capacity or to ensure that adequate nutriments are available at all times, it may be necessary to apply supplemental feeds.

Farmers use fertilizers to increase the naturally occurring food organisms in the rice field and supplements to feed the fish directly. The use of supplemental feeds is necessary if a certain degree of intensification is desired since the natural food in a rice field is not sufficient to support a higher biomass of fish. Supplemental feeding functions in much the same way in rice fields as it does in fishponds.

Diana et al. (1996) found that starting supplemental feeding late had little effect on the final harvest and since fish culture in rice fields is often limited in duration by the rice growing cycle (120 days), this has two implications. First, if the rice field is used as a nursery for the growing of fry to fingerlings, feeding may not be necessary for as long as the field is adequately fertilized. Second, if older fingerlings are used to grow food fish, feeding is essential from the very start.

Table 5. Diets reported for adult tilapias in natural habitats (Bowen 1982).

Species	Diet	Reference
T. rendalli	Macrophytes, attached periphyton	Caulton (1976, 1977); Denny et al. (1978)
S. mossambicus	Macrophytes, benthic algae, phytoplankton, periphyton, zooplankton, fish larvae, fish eggs, detritus	Bowen (1979, 1980); Man and Hodgkiss (1977); Munro (1967); Naik (1973); Weatherley and Cogger (1977)
S. aureus	Phytoplankton, zooplankton	Fish (1955); Spataru and Zorn (1976, 1978)
S. niloticus	Phytoplankton	Moriarty and Moriarty (1973)
T. zillii	Macrophytes, benthic invertebrates	Abdel-Malek (1972); Buddington (1979)

Table 6. Estimates of fish production from natural food in rice fields (Li and Pan 1992).

Carp species	Type of Food	Potential Fish Production (kg·ha-1)	Utilization Rate (%)	Food Conversion Factor	Potential Fish Production	
					Ave.	Max.
Grass	Aquatic Weeds	30 000-53 000	65	120	78	195
Silver	Phytoplankton	9.3	70	40	30	59
Bighead	Zooplankton	15	25	10	7.5	16
Common	Benthos		4	25	45	118.2
Total					160.5	388.2
Add: Detritus and bacteria[a]					48.2	117.2
Grand total					**208.7**	**504.2**

[a] Approximately 30% of total fish production

Supplemental feeds often consist of what is available in the locality. Consequently rice bran is a common supplemental feed in practically all rice producing countries. In Bangladesh, wheat bran and oil cake are used as well (Gupta et al. 1999) and in the Philippines, where coconut is an important product, copra meal (Darvin 1992) is employed. In China, feed may consist of wheat bran, wheat flour, oilseed cakes (rapeseed, peanuts, soybeans, for instance), grasses and green fodder (Wang and Zhang 1995; Li et al. 1995; Chen et al. 1998; He et al. 1998); and in Malawi, maize bran and napier grass (Chikafumwa 1996), to name a few examples. Wang and Zhang (1995) showed that the use of supplemental feeding results in higher survival rate of 67% as against 56.1% without supplemental feeding and with a corresponding increase in unit yield of 337.5 kg · ha^{-1} and only 249 kg · ha^{-1}, respectively.

Formulated diets in mash, crumble or pellet form are now increasingly used because of their greater availability. Although more expensive than farm by-products, they have the advantage of being available at the volume required if needed and are more convenient to store, handle and apply.

For more details on the types of supplemental feed, the reader is directed to the extensive literature on supplemental feeding in semi-intensive pond aquaculture. In all cases of supplemental feeding it should be remembered that most feeds either incur a direct cost by having to purchase the feed, or an opportunity cost in that the input could be put to other uses (for example fed to livestock) or sold. In addition, when employing supplemental feeds, the water quality may become an important issue as it can deteriorate rather quickly if the field is “overfed”.

7. Rice-Fish Production

7.1 Fish Yields

Similar to most aquaculture operations, the amount of fish that can be harvested in rice-fish farms varies greatly. The harvest of aquatic animals from any rice field is a function of several factors such as: water depth and water supply, presence of predators, species, stocking density, whether monoculture or polyculture is practiced, size of fish at stocking, and the rearing period. Seasonal variations in natural productivity, and whether fertilization and/or supplemental feeding have been applied also affect fish production.

Table 7 attempts to combine yields for several systems in different countries, but these figures are only indicative and great variations exist between identical systems even within the same country. The total production figures are only one aspect of the issue. The production costs as well as the value of the product are other important aspects.

7.1.1 Rice-fish

Fish production varies with stocking density, size at stocking and whether or not supplementary feeds were used. Without feeding the production per crop can range from 100 to 750 $kg \cdot ha^{-1} \cdot yr^{-1}$ (Zhang 1995), with feeding the result might be 1 812 $kg \cdot ha^{-1} \cdot yr^{-1}$.

In the Indonesian *minapadi* system, the yield varies from 75 to 100 $kg \cdot ha^{-1}$ and the fish weight between 50-70 g. Where *O. mossambicus* is stocked instead of carp, the first stocking is made with 1 000 to 10 000 fry together with a few hundred adults per hectare. Six weeks later the largest are harvested for consumption and the rest restocked for further growing (Khoo and Tan 1980).

In Basse Casamance, Senegal, rice–fish alternating with fish only culture results in fish yields ranging between 963-1 676 $kg \cdot ha^{-1}$ in ponds fertilized with animal manure and fed farm by-products, and 590 $kg \cdot ha^{-1}$ from the rice field. A typical harvest would consist of *Sarotherodon melanotheron* (50%), *O. guineensis* (40%), *Hemichromis fasciatus* (2%), *Mugil* (5%) and *Penaeus notialis* (3%). In addition, fry and fingerlings may also be present and may constitute from 5-8% of the harvest (Diallo 1998).

Stocking of large fingerlings directly into rice fields in Thailand yielded from 146-363 $kg \cdot ha^{-1}$, while growing fry in a nursery pond before transferring to rice fields ranged from 88-263 $kg \cdot ha^{-1}$. Rice yields were noted to have increased on subsequent studies (Deomampo 1998).

In Iran, production averaged 1 580 $kg \cdot ha^{-1}$ with feeding and 695 $kg.ha^{-1}$ of fish without (172 days culture period) and a rice yield of 7 014 $kg \cdot ha^{-1}$ (personal communication, Mr Ibrahim Maygoli , Shilat Aquaculture Division Head, Tehran, Iran, 30 August 1999).

7.1.2 Rice-fish-azolla

Fish yields using azolla vary widely. Liu (1995) reported fish yield of 1 000 $kg \cdot ha^{-1}$ by stocking a species-mix consisting of 100 *H. molitrix* and 300 *C. carpio* with 100 *C. idellus* and 7 500 *O. niloticus*. This was attributed to the different species complementing each other according to their feeding habits and efficiency. Both fish and rice yield were found by Yang et al. (1995) to vary with ridge width or ditch width. At constant ditch width, fish production varied from 841 kg to 736 kg to 676 $kg \cdot ha^{-1}$ at 53 cm, 80 cm, and 106 cm ridge width respectively while rice yields varied from 13-14 t. At constant ridge width of 53 cm, fish yields were 613 kg, 702 kg and 784 kg respectively for ditch widths of 40 cm, 46 cm and 106 cm respectively while rice yields varied from 9.4 to 10.1 and 10.4 t.

Wang et al. (1995) reported that fish yields also vary according to the species cultured and the stage at which they were harvested. Output of fish was highest in the rice-azolla-food fish at 536 $kg \cdot ha^{-1}$ followed by rice-azolla-*C. carpio* fry at 419 kg and rice-azolla-catfish (*C. gariepinus*) fry at 324 kg. The lowest fish yield was obtained with *C. gariepinus* fry at 280 $kg \cdot ha^{-1}$. Wang also obtained the highest yield with African catfish fry grown in a rice field without azolla at 717 $kg \cdot ha^{-1}$. The highest fish yield was reported by Chen et al. (1995) using a polyculture of *H. molitrix*, *C. carpio* and crucian carp with 7 038 $kg.ha^{-1}$ for rice-azolla-fish as against only 4 119 $kg \cdot ha^{-1}$ for rice-fish combination. The high yields were obtained by using “fine feed” to feed pigs which produced manure for the rice fields and “beer left-overs” as supplementary feed.

Table 7. Unit production of fish in rice fields, various countries.

	Fish Yield (kg·ha^{-1})						
	Bangladesh	**China**	**India**	**Indonesia**	**Philippines**	**Thailand**	**Vietnam**
Concurrent							
Monoculture							
High Range	188-239[a]				223-263[n]		
Low Range	125-156[a]	2 000-3 100[d]		143[k]	43.7-59.7[o]		48-79[t]
Polyculture							
High Range	187-605[b]	750-1 500[e]	500-2 000[h]	2 000-3 500[l]	606-636[p]	468-1 472[r]	677[u] 187 prawn +21 fish[v]
Low Range	116 –396[b]	150-300[f]	500-700[h]		78-303[o]	87.7-363.3[s]	
Rotational							
Monoculture							
Range				80-367[m]	406-527[q]		
Polyculture							
Maximum		>1500[f]					
Range		300-450[f]	815-2 135[i]				
Concurrent-Deepwater							
Polyculture							
Range	1 320-3 211[c]	300[g]	3-1 100[j]				

a) Gupta et al. (1998), ditch or sump, using *C. carpio*, *B. gonionotus* or *O. niloticus*. High range - *boro* (dry) season; low range - *aman* (wet) season.
b) Gupta et al. (1999), ditch or sump, using two (minimum figure) or more species (maximum figure). High range - *boro* (dry) season; low range - *aman* (wet) season.
c) Gupta et al. (1999), excavated ponds with average depth of 0.5 m during dry season and minimum retention of 0.9 m for 7.93 months. Minimum figure is that of adopters; maximum, that of research farmers raising fish up to 9 months.
d) Chen (1995), based on ridge-ditch system with *Clarias leather*, feed applied.
e) Xu (1995), based on ridge-ditch system with *C. idella*, *C. carpio* and *H. molitrix*.
f) Zhang (1995), unspecified species but can be assumed to be polyculture of different cyprinids as is the usual practice in China.
g) Wan et al. (1995), based on one experimental run only using *C. carpio*+*C. carassius*+*Oreochromis* sp.
h) Dehadrai (1992), high range - *Khazan* system (brackishwater) in Goa with shrimps+perches; low range – irrigated/rainfed with murrels+ catfish+carp.
i) Dehadrai (1992), brackishwater system with *P. monodon*+mullets.
j) Ghosh (1992) lower value represents production of natural stock of unspecified species and higher value on polyculture of Indian major carps+ Chinese carps+catfish.
k) Koesomadinata and Costa-Pierce (1992) *minapadi* system with *C. carpio.*
l) Koesomadinata and Costa-Pierce (1992), based on annual yield for *sawah-tambak* with stock of *C. chanos*+*C. carpio*+*P. javanicus*+*M. rosenbergii* or *P. monodon*.
m) Yunus et al. (1992), the lower value represents *penyelang* crop and the higher value, *palawija* both using *C. carpio*.
n) Saturno (1994), wet season using pond refuge with *O. niloticus* for lower value; Israel et al. (1994) dry season using pond refuge with *O. niloticus* for higher value.
o) Fermin et al. (1992), wet season crop with trench refuge, using *C. carpio*+*O. niloticus*.
p) Torres et al. (1992) dry season crop with trench refuge using *O. niloticus*.
q) Sevilleja (1992) based on single trial using fallow ricefield to raise *C. carpio*+*O. niloticus*.
r) Fedoruk and Leelapatra (1992) based on Thailand Dept. of Fisheries 1983 figures.
s) Thongpan et al. (1992) based on on-farm rice-fish farming research in Ubon, Northeast Thailand.
t) Mai et al. (1992). *M. rosenbergii* production in ricefield canals in Mekong Delta.
u) Cantho Univ. College of Agric. (1997), pond or canals connected to ricefield using three cyprinid species.
v) Mai et al. (1992), polyculture of *M. rosenbergii* and *P. gonionotus*.

7.1.3 Rice and crustacean

Crawfish yields from rice fields range from 1 120-2 800 kg·ha^{-1} depending upon the length of the harvest period (Dela Bretonne and Romaire 1990). River or mitten handed crabs yield 227-303 kg·ha^{-1} button-crabs. The yield of marketable crabs ranges from 303-454 kg·ha^{-1} at a stocking rate of 75-150 kg·ha^{-1}. Penaeid shrimp yield in India ranges from 3 kg·ha^{-1} in deepwater rice plots relying on natural stock of mixed species to over 2 135 kg·ha^{-1} in shallow brackishwater rice fields stocked with *P. monodon* (Ghosh 1992).

7.1.4 Polyculture

Stocking multiple species or polyculture generally results in higher yields than monoculture. The high figures from the *sawah-tambak* of Indonesia and the deepwater rice in Bangladesh are all based on polyculture: *C. chanos* + *C. carpio* + *B. gonionotus* + *M. rosenbergii* or *P. monodon* in the case of Indonesia and six species of Indian and Chinese carps in the case of Bangladesh. Higher yields with polyculture of *O. niloticus* and/or *B. gonionotus* with other carps than monoculture of either species have also been reported by Gupta and Rab (1994) in Bangladesh.

Gupta et al. (1998) found the combination of any two species among *C. carpio*, *B. gonionotus*, and *O. niloticus* resulted in lower yields than only one of the species. When farmers added different carp species such as *H. molitrix*, *L. rohita*, *C. catla*, *C. cirrhosus* and *C. idella*, the production surpassed monoculture (Table 8). The apparent difference in the average production for all species is not significantly different. During the dry season 66% of the farmers preferred *C. carpio* while during wet season 54% preferred *B. gonionotus.*

In summary, it is difficult to either predict what the yield will be in any particular area or advise (without local trials) what stocking practice is the best. Overall, there are indications that polyculture gives better yields, but not any polyculture. Likewise, although increased stocking density and feed inputs increase yields (within certain limits), this has to be compared with the associated increase in costs. Usually local trials are needed to assess which would be the best mix to provide the farmer with the highest net profit and least risk.

While the magnitude of fish harvest in a concurrent rice-fish farming system may be unspectacular compared to the harvest in an intensive or even a semi-intensive pond aquaculture, this is perhaps not the main point. Rice is, after all, the main crop. What is more important is that with some additional expense and effort and without having to acquire more land, a rice farmer can actually produce fish and thus diversify the household's options in terms of food security as well as income generation. The fact that the presence of the fish may actually help boost rice production and may reduce, if not completely eliminate, the need to use pesticides and fertilizers can be seen as an added bonus.

7.2 Rice Yields

Much has been said about the mutualism of fish and rice. Mutualism implies beneficial effects on each other. Rice acts as a nitrogen sink and helps reduce the ammonia that may be released by the fish and in so doing helps make the water cleaner for the fish. Figure 13 shows the interrelationship

Table 8. Production, harvest size and recovery rate of fish at various stocking densities during boro (dry) and aman (wet) seasons in Bangladesh 1992-94. Standard deviations are in parenthesis (Gupta et al. 1998).

Species	No. of cases	Stocking Density per ha	Average weight at harvest (g)	Recovery (%)	Fish Production (kg·ha^{-1})
***Boro* seasons (1993 & 1994)**					
C. carpio	96	3 400 (1 107)	115 (56)	53.8 (24.5)	204 (133)
B. gonionotus	13	3 017 (319)	95 (72)	65.0 (22.3)	188 (154)
O. niloticus	8	3 156 (442)	108 (25)	69.5 (12.1)	239 (75)
C. carpio + *B. gonionotus*	13	3 070 (324)	107 (42)	59.3 (15.4)	187 (64)
C. carpio + *O. niloticus*	1	4 667	86	39.6	158
B. gonionotus	2	3 643 (909)	25 (4)	50.5 (35.4)	47 (37)
Multispecies	12	9 323 (7 503)	241 (255)	49.1 (24.4)	605 (385)
All	145	3 825 (2 814)	121 (96)	55.6 (23.4)	233 (197)
***Aman* seasons (1992-1994)**					
C. carpio	4	4 090 (2314)	54 (19)	76.8 (13.4)	156 (77)
B. gonionotus	53	3 130 (603)	58 (29)	66.4 (15.6)	125 (90)
C. carpio + *B. gonionotus*	20	3 771 (1611)	53 (38)	61.7 (22.0)	116 (85)
Multispecies	21	6 778 (2834)	214 (146)	34.1 (20.7)	396 (256)
All	98	4 082 (2148)	90 (97)	59.0 (22.3)	184 (179)

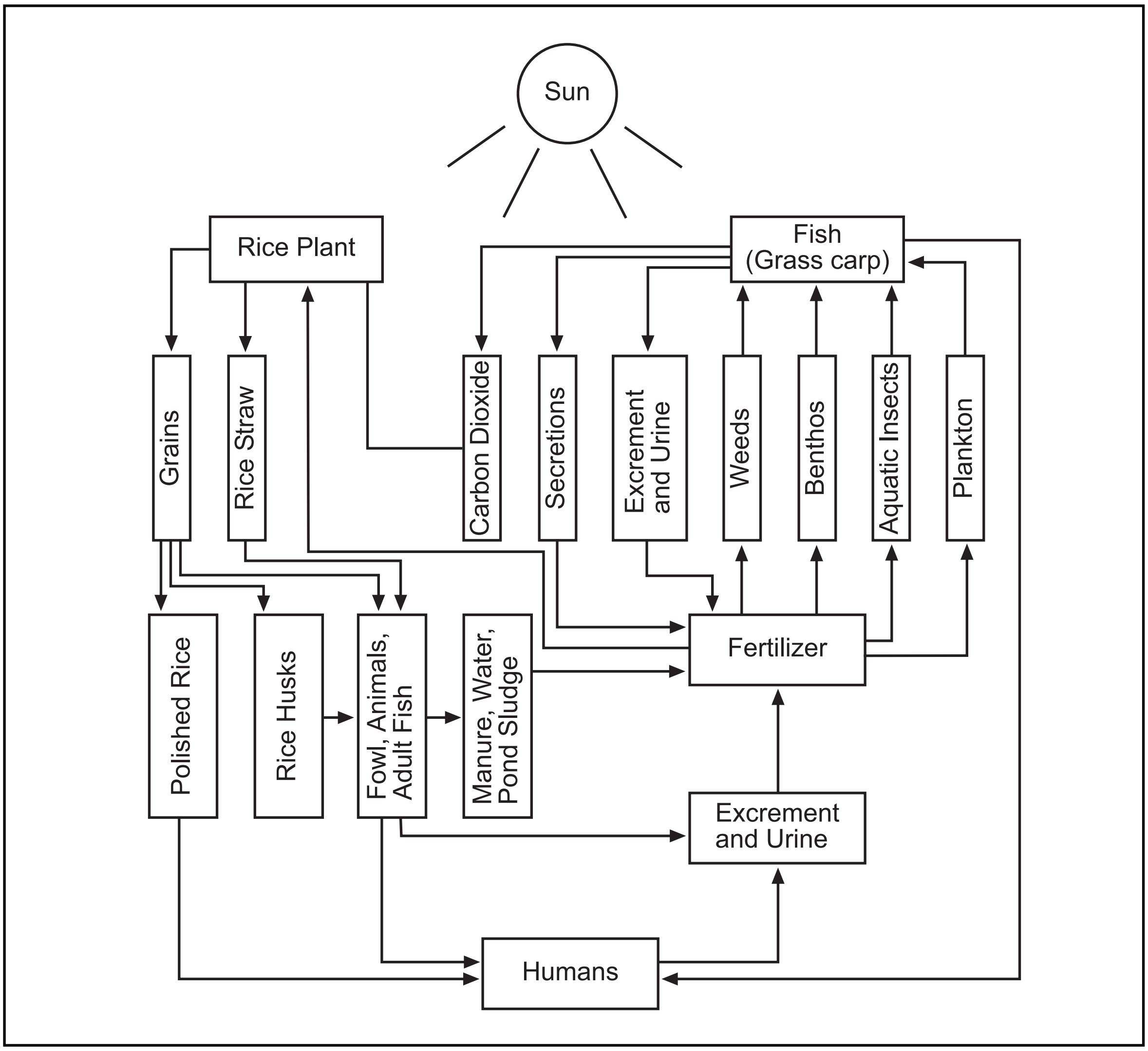

Figure 13. Flow of energy in a rice field ecosystem (Ni and Wang 1995).

between rice, fish and the environment in a rice-field ecosystem (Ni and Wang 1995). To a large extent mutualism does exist. However, this does not mean that the presence of rice necessarily makes it possible to produce more fish. To the contrary, the presence of rice hinders fish production since the biological needs of the rice and the fish are rather disparate. An example of this was found by Rothuis et al. (1998b) in Vietnam where the rice-seeding rate negatively affected the fish yield. Dense stands of rice suppressed phytoplankton growth as nutrient availability was reduced, shading increased and the access of fish into the rice field restricted. Without rice, the rice field can be managed like a fishpond and higher fish yields may be expected.

It would seem a simple matter to obtain a definitive answer to what happens to the rice when fish are stocked considering the growing body of literature on rice-fish farming. Unfortunately it is not so simple. While many of the papers available have specific figures on rice yields of rice-fish farms, only a few have any information on what the rice yields would have been without the fish under the same circumstances or what may be considered control figures. Often the assertions are anecdotal. As Lightfoot et al. (1992) pointed out, “many authors have quoted farmers (or quoted other authors who quoted farmers) to elevate to the status of conventional wisdom the increase in rice yield when fish are stocked.”

From the nearly 200 documents consulted, only 18 had control figures based on first-hand data that could serve as a basis for obtaining a clearer picture on the effects of fish on rice yield. The 18 documents include two graduate school theses and one annual report in addition to some scientific papers presented in symposia, workshops or conferences covering five countries. The selection of paired data where both the rice-fish culture and rice-only culture were done by the same farmer is important in order to remove the “skill factor”. As Waibel (1992) has pointed out, it is possible that farmers who adopted rice-fish farming are just better farmers.

It is well to start with the Philippines that has the earliest comparative rice yield figures. In trials using *O. niloticus* throughout the Philippines, on average the rice yield was not significantly lower in rice-fish plots (NFAC 1980). More recent studies have consistently shown higher rice yields in rice-fish fields than in rice-only fields, between 14-48% (Table 9a). The same pattern of increased rice yields in fields with fish has emerged from Bangladesh (Gupta et al. 1998).

Studies in China follow the trends in the Philippines and Bangladesh with some exceptions (Table 9b). All provinces, apart from Jiangsu, showed higher yields with fish than without them. In West Bengal, India, field trials in deepwater rice testing the effect of supplementary feeding on the fish stocked resulted in 4-11% higher rice production in the rice-fish plots in both with and without feeding. However, rice yields were slightly lower (by 2-5%) in rice-fish using cow-dung (poor in nitrogen and phosphorus) as fertilizer, but higher (8-43%) using chicken manure rich in nitrogen and phosphorus (Mukhopadhyay et al. 1992).During the dry seasons of 1993 and 1994, an average of 82.4% of 34 farms practicing rice-fish farming reported higher yields in fields with fish. During the wet seasons of 1992 to 1994, 56.2% of 25 farms reported higher yields. Rice yields in the fields with fish were, on average, higher by 6.4% during the dry season in 1994 and 19.5% in 1993, and during the wet season, 12.7% in 1992 and 9.8% in 1993 (Gupta et al. 1998) as shown in Table 10.

In Indonesia, side-by-side trials consistently showed higher rice yield (22-32%) in the rice-fish plots compared to control plots without fish (Fagi et al. 1992), regardless of season and whether the plots were weeded or not, or whether herbicides were used or not. Purba (1998) concluded in his study in North Sumatra that although the rice-fish system decreases the effective area for growing rice, its impact on the total rice production of the country is minor and can be ignored. In Thailand, under all topographic conditions rice yields were, on average, higher in rice fields stocked with fish (Thongpan et al. 1992). In Vietnam, the yield was lower, but statistically significant. The rice yield was observed in rice fields with *B. gonionotus* (Rothuis et al. 1998c), but there was no control without fish.

In order to obtain an overall perspective of the situation, the frequency distribution of the percentage increase in rice production was determined when fish were present. Data from the trials were averaged considering only one variable, with or without fish. However, for trials with treatments, for example use of different fertilizers, the result of each treatment was entered separately. Although this approach may not be rigorous enough for the result to be considered as definitive by some purists, by pooling the results of the various workers from five different countries in Asia an overall picture of the impact of rice-fish farming on rice is possible (Figure 14).

The analysis demonstrates that, although higher rice yields were not always obtained with the introduction of fish, the majority (80%) resulted in higher yields of 2.5% or more. The results seem convincing enough: growing fish in rice fields does generally result in higher yields than growing rice without fish.

These results indicate that although the area for rice cultivation is decreased in rice-fish culture, the mutualism with fish possibly together increases inputs and/or better management and more than compensates for this loss in area through greater yield. The increase in yield in turn seems to be due to the increased number of grains per panicle[13] (Table 11) and possibly in combination with a decrease in the incidence of whiteheads[14] (Magulama 1990).

In summary, rice fields where fish are stocked will likely have a higher yield because the rice field will have less weeds and less stemborers. Less weeds to compete with the rice for soil nutrients and less pests cannot but contribute to the production of more and bigger grains, and a reduced occurrence of unfilled grains. In short, rice fields with fish have healthier rice plants than those without fish.

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[13] A panicle is defined as the terminal shoot of a rice plant that produces grains.

[14] Whiteheads are empty panicles and are so called because of the appearance of the afflicted rice plants. They result mainly from stemborer attacks that cause the lower portion of the rice stems to be cut. Drought and desiccation may also cause whiteheads.

Table 9a. Effect of fish on rice yield, paired results from various places 1977-94.

System/Location/Year	Rice Yield (kg·ha^{-1})			References
	With fish	W/out fish	More (Less)	
BANGLADESH				
S/D[a], Mymensingh/Jamalpur, dry 1993-94	4 980	4 555	425	Gupta et al.1998
S/D[a], Mymensingh/Jamalpur, wet 1992-94	3 811	3 496	315	-ditto-
INDIA				
Sump[b]/no feed, Chinsura 1987	1 729	1 574	155	Mukhopadhyay et al 1992
Sump/fed, Chinsura 1987	1 741	-ditto-	167	-ditto-
Sump/no feed, Gosaba 1987	2 122[b]	2 039	83	-ditto-
Sump/fed, Gosaba 1987	2 130[b]	-ditto	91	-ditto-
Sump/cd[d], Sabang 1987	1 602	1 677	(75)	-ditto-
Sump.cm[d], Sabang 1987	2 399	-ditto-	722	-ditto-
Sump/cd, Girirchalk 1987	2 850	2 920	(70)	-ditto-
Sump/cm, Girirchalk 1987	3 160	-ditto-	240	-ditto-
INDONESIA				
Tr/0-w[e], Sukamandi, wet 1988-89	6 620	5 430	1 190	Fagi et al 1992
Tr/1-w[e], Sukamandi, wet 1988-89	7 130	6 700	430	-ditto-
Tr/2-w[e], Sukamandi, wet 1988-89	7 380	7 300	80	-ditto-
Tr/wcide[e], Sukamandi, wet 1988-89	7 280	6 970	310	-ditto-
Tr/0-w, Sukamandi, dry 1989	4 220	3 430	790	-ditto-
Tr/1-w, Sukamandi, dry 1989	4 690	4 170	520	-ditto-
Tr/2-w, Sukamandi, dry 1989	5 570	5 280	290	-ditto-
Tr/w-cide, Sukamandi, dry 1989	4 970	4 560	410	-ditto-
Trench/TSP[f], Sukamandi, dry 1989	7 994	6 060	1 934	-ditto-
PHILIPPINES				
Trench, 11 regions[g] 1977-78	5 739	5 939	(200)	NFAC 1980
Trench, Cavite 1986-87	7 100[h]	4 750	2 350	Fermin 1992
Trench, 20 x 20[i], Laguna 1988	2 392	2 348	380	Magulama 1990
Trench, 40 x 10[i], Laguna 1988	2 693	2 199	494	-ditto-
Trench, 30 x 10[i], Laguna 1988	3 142	2 381	761	-ditto-
Trench, 20 x 15[i], Laguna 1988	2 431	2 431	0	-ditto-
Trench, Nueva Ecija 1989	6 300	6 200	100	Torres et al. 1992
Pond[j], Nueva Ecjia 1989	6 100	“	(100)	-ditto-
Pond[j], Nueva Ecija, wet season 1990[k]	4 929	4 177	752	Israel et al. 1994
Pond[j], Nueva Ecija, dry season 1991[k]	6 098	4 294	1 804	Israel et al. 1994
THAILAND				
ns, Dom Noi, wet 1985	1 890[l]	1 790	100	Thongpan et al. 1992
ns, Khoo Khad, wet 1985	1 630[l]	1 510	120	-ditto-
ns, Amnart Charoen 1987	2 537[l]	2 014	523	-ditto-
ns, Kheuang Nai 1987	2574[m]	2 372	202	-ditto-
ns, Det Udom 1987	2 651[m]	2 427	224	-ditto-

Legend: TSP - triplesuperphosphate

a) Sump or ditch, involved 107 farms during 3 rainy seasons (*aman*) in 1992-94 and 149 farms for 2 dry seasons (*boro*) in 1993-93.
b) Central sump provided, deep water rice used.
c) Average of two plots.
d) Composted cow dung (cd) and dried chicken manure (cm) tested as fertilizers.
e) Trench, 0-w, 1-w, 2 w (0, 1 & 2 weeding respectively); w-cide (herbicide used).

f) 7 levels of TSP against 1 control, w/fish rice-yield figure is average of 7 levels .
g) Nationwide field testing in 13 pilot provinces, figures represent average of 15 field-test results.
h) Average of 1986 and 1987 runs.
i) Refers to the four rice-planting patterns tested.
j) Pond refuge within ricefield.
k) Average harvests from 15 farmers using pond refuge.
l) Average harvest of 12 farmer cooperators in Khoo Khad and 13 in Amnart Charoen.
m) Average of tests using 5 different rice varieties in Kehung Nai and 3 in Det Udom.

Table 9b. Effect of fish on rice yield, results from China, 1980-87.

System/Location/ Year	Rice Yield (kg/ha)			Reference
	With Fish	W/out Fish	More (Less)	
Tr, Hunan, early 1980-83	3 272	2 734	538	Nie et al. 1992
Tr, Hunan, median 1980-83	5 596	5 138	458	-ditto
Tr, Hunan, late 1980-83	8 595	6 218	2 377	-ditto
ns, Hubei 1983	7 774[a]	6 375	1 398	Wu 1995
ns, Hubei 1984	7 569[a]	6 573	996	-ditto
RAF, ns. 1985-86	7 096	6 493	603	Wang et al. 1995
ns, ns 1985-86	6 905[f]	-ditto-	411	-ditto-
Tr w/sump[b], Jiangsu 1985	8 667	9 054	(387)	Li et al. 1995
Tr w/ sump Jiangsu 1986	7 884	7 929	(45)	-ditto-
Tr w/sump, Jiangsu 1987	7 998	7 996	(2)	-ditto-
Rdg, Anhui 1987	7 125	6 150	975	Yan et al. 1995
WRdg, Anhui 1987	6 870	-ditto-	720	-ditto-
Bed, Anhui 1987	6 990	-ditto-	840	-ditto-
Conventional, Anhui 1987	6 795	-ditto-	645	-ditto-
R/D, Guilin, early 1987	7 632	6 135	1 497	Cai et al. 1995
R/D, Guilin, late 1987	6 750	6 225	525	-ditto-
R/D, Wuzhou, early 1987	11 654	11 037	617	-ditto-
R/D, Wushou, late 1987	6 606	6 206	400	-ditto-
R/D, Qinzhou 1987	5 537	4 857	680	-ditto-
Tr, Yunnan 1986	6 500	5 800	700	Chen 1995
Tr, Yunnan 1987	7 100	6 400	700	-ditto-
Tr, Yunnan 1988	7 000	6 500	500	-ditto-
ns, Hubei 1988	8 250	7 650	600	Lin et al. 1995

LEGEND: Tr-trench; RAF- Rice-azolla-fish; Rdg-ridge; WRdg-wide ridge; R/D –ridge/ditch; ns – not specified.
a) Average of two treatments.
b) X-trench 0.33 m wide x 0.4 m deep w/ sump (2.5x1x1m) at intersection.

Table 10. Rice yields from integrated and rice-fish plots and mono-cropped rice plots. Ranges are in parentheses (Gupta et al. 1998).

Season	Year	No. of Cases	Rice yield ($kg.ha^{-1}$)		Cases with higher yields from integrated plots (%)	Mean difference in yield from control (%)
			Control plot	Integrated plot		
Boro (Irrigated)	1993	10	3 957	4 651	70.0	+19 (-13.3 to +57.6)
	1994	24	4 804	5 117	87.5	+ 6.4 (-30.0 to +19.0)
	All	34	4 555	4 980	82.4	+10.25 (-13.3 to 57.6)
Aman (Rainfed)	1992	15	3 749	4 108	67.0	+12.7 (-21.3 to +55)
	1993	10	3 121	3 364	40.0	+ 9.9 (-30.6 to –66.7)
	All	25	3 498	3 811	56.2	11.6 (-21.3 to 66.7)

Table 11. Comparative characteristics of rice grown with and without fish, the Philippines and China (data sources as indicated in table).

	No.Grains per Panicle		% Empty Grains		1000-Grains wt (g)	
	Rice-Fish	Control	Rice-Fish	Control	Rice-Fish	Control
WU 1995						
Early-1	94.0	87.0	8.4%	13.0%	24.8	24.8
Early-2	107.0		7.8%		24.8	
Late –1	104.0	111.6	19.7%	21.4%	28.5	28.6
Late- 2	116.8		19.0%		28.7	
YAN ET AL. 1995a						
Ridge	107.9	105.0	18.6%	21.6%	30.2	29.0
Wide Ridge	115.6		19.7%		28.6	
Bed	112.2		23.2%		30.0	
Conventional	114.0		25.6%		29.1	
LI ET AL. 1995						
1985	153.3	152.2	10.9%	8.6%	29.1	29.8
1986	138.3	142.6	12.4%	12.1%	28.6	28.2
1987	152.5	152.7	17.4%	16.4%	28.8	28.9
CAI ET AL. 1995a						
Guilin, early	126.0	117.0	13.6%	17.7%	28.3	27.8
Guilin, late	118.0	105.0	17.9%	21.6%	27.0	26.9
Wuzhou, early	124.3	118.4	11.0%	12.5%	25.6	24.8
Wuzhou, late	127.7	109.6	19.8%	21.2%	25.3	24.8
Qinzhou	125.4	121.1	17.0%	27.8%	26.6	25.3
	No. Grains per m^2					
MAGULAMA 1990						
20 x 20[a]	30 535	26 121	26.1%	32.0%	25.4	25.0
40 x 10	37 954	28 352	23.5%	33.4%	25.1	24.5
30 x 10	44 175	31 642	23.2%	33.5%	25.1	24.9
20 x 15	37 107	34 546	24.8%	32.0%	24.8	24.8

a) Treatment consisted of planting patterns, numbers refers to rice plants.

SUMMARY:
Total number of data rows: 20
No. of grains/panicle:
    Total instances higher in rice+fish plot: 17
    Average percentage higher in rice +fish plot: 9.9%
% empty grains
    Total instances lower in rice+fish plots: 15
    Average percentage lower in rice+fish plots: 13%
1000-grain weight
    Total instances higher in rice+fish plot: 13
    Average percentage higher in rice+fish plots: 1.1%

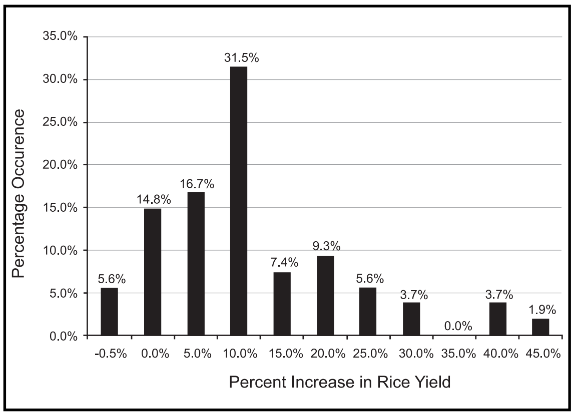

Figure 14. Frequency distribution of percentage increase in rice yield as a result of raising fish in a rice field based on published data from China, India, Indonesia, the Philippines and Thailand, 1977 to 1992 as summarized in Tables 9a and 9b.

8. Pest Management

8.1 Managing Pests with Fish Present

Pest management includes many options falling into four major categories: mechanical, chemical, cultural and biological. The first is the most widely used and the one with the longest tradition, together with natural control that is considered part of biological control. Weeding is perhaps the best example of this, but also includes cultural techniques such as water level control. Chemical pest management is relatively new and widespread, particularly popular for its perceived effectiveness and for the fact that it is not labor intensive. Unfortunately, insecticide applications in rice have been proven to become a major problem because they destabilize the ecosystem and trigger pest resurgence thus creating an even more critical situation than without their use. Biological control of pests has a range of applications from favoring certain organisms that are predators of certain pests, to use of disease resistant rice varieties. Particularly when pesticide-related health impairments are included, natural control is the most profitable option for farmers (Rola and Pingali 1993). An integrated approach using various management options termed Integrated Pest Management or IPM is the preferred choice for plant protection in rice,[15] and in fact has been adopted as the national plant protection strategy by most rice-producing countries.

Integrated pest management[16] encompasses all four management options outlined above and attempts to optimize their use. The following sections will examine the available options and their established or potential impact on fish in the rice field. The main pest organisms to manage are weeds, pathogens and invertebrates (mainly snails and insects); although rats and crabs may also cause a lot of damage in some areas.

One reason why farmers can no longer catch fish in their rice fields like they used to, especially if irrigation comes from river water, is the increased use of pesticides. The use of chemicals is often cited as one of the major constraints in the popularization of rice-fish farming (Koesomadinata 1980; Cagauan and Arce 1992). Yet stocking fish in rice fields actually reduces pest infestation, and thus also reduces if not eliminates the need for application of herbicides and insecticides and particularly molluscicides where snail predatory fish are cultivated (Waibel 1992; Cagauan 1995; Halwart 2001a, b, 2004a). The practical and economic advantages of using fish instead of chemicals are often obvious.

The effectiveness of fish as a bio-control agent depends on how well they are distributed within a rice field. If fish stay mostly in the pond refuge then they cannot be effective in controlling rice pests. Halwart et al. (1996) found that in rice fields provided with a 10% pond refuge, and stocked with either *C. carpio* or *O. niloticus*, more fish were present among the rice plants than in the pond. Since feeding is a major impulse for the diurnal activity of the fish, the distribution pattern supports the hypothesis that fish are potentially important in controlling pests.

Although farmers stocking fish tolerate a higher level of pest infestation before spraying is economically justified (Waibel 1992), a high level of pest infestation is always a possibility. In such a situation, the use of pesticides as well as other control methods should be considered based on the potential costs and losses in terms of rice yield and fish harvest. The important characteristics to be considered in the selection of any pesticide to be applied in a rice-fish farm can be summed up as follows:

- relative safety to fish - should be tolerated by fish at the recommended dosage effective against the target insect species;
- rate of bio-accumulation - should not accumulate or persist in rice and should be metabolized into non-toxic compounds and excreted by fish; and
- rate of degradation and persistence - should either volatilize, bio-degrade or chemically

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[15] Except in organic farming practices.

[16] IPM means "the careful consideration of all available pest control techniques and subsequent integration of appropriate measures that discourage the development of pest populations and keep pesticides and other interventions to levels that are economically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy crop with the least possible disruption to agro-ecosystems and encourages natural pest control mechanisms." - FAO International Code of Conduct on the Distribution and Use of Pesticides.

degrade shortly after its application, preferably within a matter of days.

There are of course other factors such as safety for humans and livestock and relative efficacy are also important considerations, which, at any rate, apply whether or not fish are cultured with rice.

There are four major groups of pesticides used in rice fields: herbicides, insecticides, fungicides and molluscicides. Herbicides are considered the least toxic and insecticides generally the most toxic to humans. Current changes in rice culture including high labour costs and increasing nitrogen fertlilization appear to be resulting in increased herbicide and fungicide use, respectively. Several herbicides and fungicides are known to have high non-target toxicities and therefore need to be critically examined.

Rice-fish farmers tend to avoid pesticides, mainly because the risk of killing the fish is high particularly when pesticides with high fish toxicity are applied. The use of non-toxic or low-toxic compounds is viewed cautiously as well since even though the consumption of contaminated fish is not likely to cause immediate death or illness it may result in residues and bio-accumulation of these so-called “safe” pesticides.

In the aggregate, most countries today favor IPM practices and particularly when fish are stocked in rice fields the natural control option has been shown to be the most profitable choice for farmers. In cases where the use of pesticides may be the only option, precautionary measures should be in place to safeguard the fish[17] and other non-target organisms as well as the consumers’ health.

8.2 Management of Rice Field Weeds

There are several practical options in controlling weeds in rice fields: land preparation, water depth variation, mechanical weeding, herbicide use and stocking of herbivorous fish.

At a water depth of 15 cm or more, weed species such as *Echinochloa crusgalli* stop growing and most plants die (Arai 1963). Manna et al. (1969) also reported how water depth negatively affected the incidence of grass weeds and sedges in rice fields. The fact that a rice field stocked with fish needs a certain water depth generally makes the control of weeds easier.

Mechanical weeding is perhaps the most frequently used way of controlling weeds, and although stirring up the water and causing turbidity may affect fish growth negatively, the frequency is unlikely to significantly impact on the fish production. It is, however, a very labor intensive way of controlling weeds and as such often carries a high opportunity cost (particularly in areas integrated in a cash economy).

Herbicides are used extensively, but are not considered a serious problem in rice-fish farming. If a herbicide is applied, it is normally done immediately after transplanting. Fish are stocked 10 to 14 days after application (Torres et al. 1992). Further, it is also possible to select a herbicide which can be tolerated by fish even at relatively high levels. Cagauan and Arce (1992) together with Xiao (1992) listed nine types of herbicides being used in rice culture in Asia.

Tests showed that *C. carpio*, *M. rosenbergii*, and a freshwater clam (*Corbicula manilensis*) have very high tolerance limits for 2,4-D or MCPA (Chlorophenoxyacetic acids) (Cagauan and Arce 1992; Xiao 1992). 2,4-D’s toxicity to aquatic organisms depends on the species of organism, the formulation of the chemical, and the surface water system parameters such as pH, temperature, and water chemistry. 2,4-D is readily excreted in the urine of animals and does not bio-accumulate. However, some authors (for instance Beaumont and Yost 1999) maintain that the 2,4-D type of herbicides have been associated with cancer, citing several writers to support their contention that these types of chemicals are tumor promoters. 2,4-D is currently in a re-registration process with the US EPA.

Introducing fish to the rice field can reduce the amount of weeds in several ways. To the herbivorous species of fish, weeds are part of their diet. To bottom feeding species, weeds just happen to be in the way. In the process of looking for food, the muddy bottom of a rice field is tilled giving little chance for the submerged weeds to anchor their roots in the soil thus affecting their growth and proliferation. In rice fields stocked

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[17] In order to ensure the safety of the fish, most writers recommend that the fish be concentrated in the trenches, sumps or ponds prior to spraying and a temporary embankment built to prevent the water from the rice field getting into the fish refuge. Only when the toxicity of the pesticide has dissipated, are the fish allowed to return to the rice field.

with *B. gonionotus* and *C. carpio* in Bangladesh, farmers have observed that weeds are eaten directly by the fish or are uprooted and die off when the soil is disturbed by the browsing fish - resulting in reduced weed infestation (Gupta et al. 1998).

In China, fish have been found to be more effective in weed control than either manual weeding or use of herbicides. *C. idellus* was the most effective species for this purpose and especially effective for controlling 21 different species of weeds, such as E*chinochloa crusgalli, Eleocharis yokoscensis, Cyperus difformis, Rotala indica, Sagittaria pygmaea, Monochoria vaginalis,* and *Marsilea quadrifolia*. The introduction of fish reduced the amount of weeds in one rice field from 101 kg to only 20 kg after five weeks, while in an adjacent rice field with no stocked fish the weed biomass increased from 44 kg to 273 kg during the same period (Wu 1995).

C. carpio eat young roots, buds and underground stems of weeds in the rice field, although ingestion may be incidental rather than deliberate as they forage on benthic organisms. Only weeds with their roots anchored to the soil (such as Cyperaceae and Poaceae families) are foraged but not free floating weeds (Satari 1962).

O. mossambicus and the Redbelly tilapia (*T. zillii*) can also be used to control weeds. *T. zillii* is especially effective (Hauser and Lehman 1976). *O. niloticus* is not regarded as a weed feeder and is more effective in consuming blue-green algae (Anon. 1971 as cited by Moody 1992), although Magulama (1990) found that it can also contribute to the reduction of weeds. Two other species found to be effective in weed control are *B. gonionotus* and *Trichogaster pectoralis* (Khoo and Tan 1980).

8.3 Management of Invertebrates

Insects and other invertebrate pests, primarily snails and, in certain areas, crabs may cause damage to the rice crop during particular growth stages. The following section deals primarily with the management of insect and snail pests.

The application of pesticides to reduce insects and other invertebrates has several consequences that are of importance to rice-fish culture, since some of the pesticides directly affect the fish and in other cases reduce the food organisms for the cultured species.

8.3.1 Management of insect pests

Insect pests may be classified into two general types: those that affect rice production and those that do not but are nevertheless considered as pests because of public health reasons, for instance mosquitoes. The effectiveness of fish in controlling insect pests is influenced by hydrological, biological and agricultural factors. Fish have been shown to play a significant role in reducing some insect species populations in rice fields. Their interaction with beneficial organisms is less clear. It should be noted that insect pest-predator dynamics are usually well balanced in a rice ecosystem that is not disrupted by the use of insecticides. Halwart (1994a) concludes that the presence of fish in flooded rice further reinforces the stability and balance of pest-predator interactions in the ecosystem.

In Bangladesh, the population of useful insects such as lady beetle, spider and damsel fly, was 5-48% higher in rice-fish farms compared to rice-only farms 10-12 weeks after transplantation, but later on the converse was observed. However, pest infestation was 40-167% higher in rice-only farms during all stages of rice growth (Gupta et al. 1998).

Mosquitoes and midges pass part of their life-cycle in the water and while not considered harmful to rice plants, they are still considered as pests. Some early work on stocking fish in rice field was mainly aimed at controlling mosquitoes rather than producing food fish with the exception of China where combined raising of *Gambusia* and common carp resulted in the reduction of anopheline and culicine larval populations by 90 and 70%, respectively (WHO 1980 in Pao 1981). The rice planthoppers and leafhoppers usually rest on the middle or lower parts of the rice plants to suck plant juices during the day and climb to the upper part of the rice plant to feed at night or in the early morning. *C. carpio* and *C. idellus* over 6.6 cm in length were found to be effective in reducing planthoppers and leafhoppers, respectively (Xiao 1992). *C. idellus* are the most effective fish against the hoppers followed by *C. carpio* and *O. niloticus* (Figure 15). Yu et al. (1995) suggest that *C. idellus* are effective because of consuming the outer leaves of the rice plants where the planthoppers oviposit their eggs. In addition, the fish also consume planthoppers that fall down in the water. So as not to depend purely on chance, Xiao (1995) recommends that "a rope be pulled over the rice plants" in order to

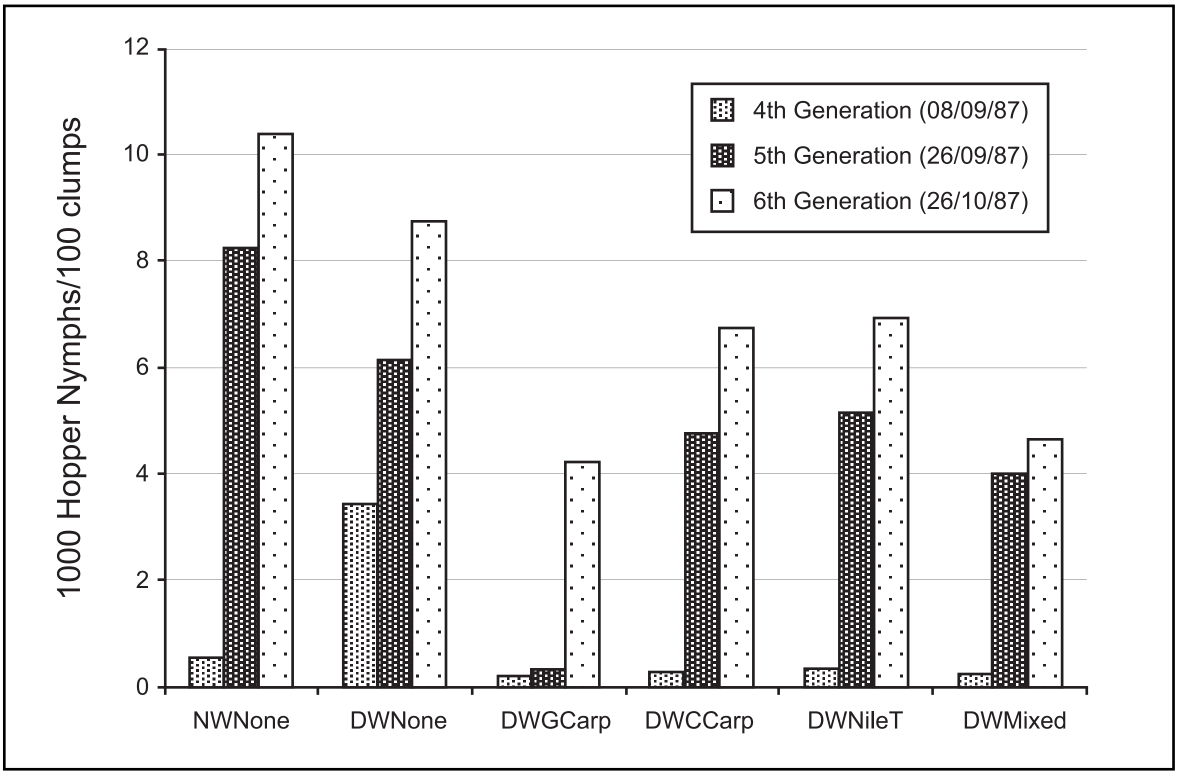

Figure 15. Effect of different species of fish on rice planthopper nymphs in rice+fish farms. NW -- normal water depth, DW—Water kept at 10 cm, None – No fish, GCarp – Grass Carp, CCarp – Common Carp, NileT- Nile Tilapia, Mixed – All 3 Species. Shangyu County, Zhejiang Province, China (data source: Yu et al. 1995).

drive the planthoppers down to the water surface where they are accessible to the fish. In Vietnam, a rice-fish farm recorded 3 800 hoppers$\cdot$m^{-2} as against hundreds of thousands of hoppers$\cdot$m^{-2} in surrounding infested areas (Tuan 1994).

Yu et al. (1995) report that observations in China indicate 47-51% less stemborers in rice-fish fields compared to rice-only fields. They also found a reduction of between 28-44% in the attack rate compared to rice-only fields. Magulama (1990) observed that whitehead incidence, a clear sign of stemborer infestation, in experimental plots in the Philippines was 11% in rice-fish fields and 18% in rice-only plots (Figure 16). Halwart (1994a) observed low stemborer infestation levels in both rice-only and rice-fish treatments in three consecutive seasons. In the fourth season, however, he noted a statistically significant 3% reduction in yellow stemborer (*Scirpophaga incertulas*) infestation as whiteheads in rice fields with *O. niloticus* and 5% lower with *C. carpio* compared to control fields without any fish where an 18% infestation was prevalent. The control mechanism is likely to be predation by fish on the neonate stemborer larvae which, after hatching, often suspend themselves from the rice leaves with a silken thread to disperse to other hills.

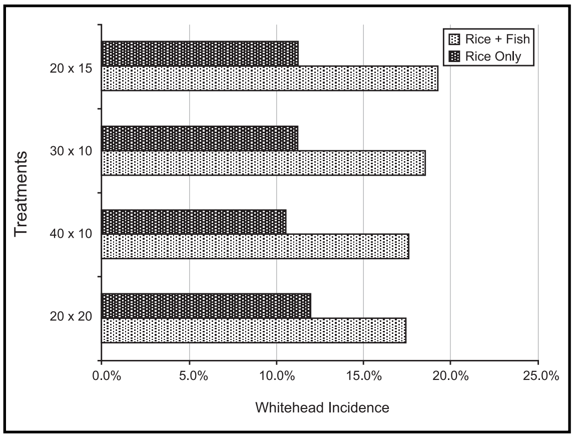

Figure 16. Incidence of whiteheads on rice plants in fields stocked with Nile tilapia and in fields without fish (data source: Magulama 1990).

Conversely, the number of leaffolders (*Cnaphalocrocia medinalis*), sometimes also called leaf rollers, was actually higher in rice-fish fields than in rice-only fields in China. Rice-fish fields had 90 to 234 leaffolders per 100 hills as against 12 to 149 in rice-only fields. Fish apparently do not eat the leaffolder larvae while the presence of fishwaste and deep water may have favored oviposition, hatching and feeding of the insect larvae. However, Hendarsih et al. (1994) noted that damage to rice due to leaffolders was 50% lower for Indonesian rice-fish farmers, although this was not found to be statistically significant.

Chemical insecticides are generally more toxic than herbicides and may have to be applied even while the fish is still growing in the rice field. Xiao (1992) maintains that pesticides are not incompatible with rice-fish culture and that these can be applied safely provided the following points are followed:

- a suitable type is selected;
- a safe dosage is used;
- proper delivery methods are used;
- application period is properly timed; and
- pre-application preparations are undertaken to protect the fish.

There has been no systematic evaluation of the different insecticides as to their toxicity to different species of fish as well as to their rate of bio-accumulation in fish. What is available are a number of tests on the more prevalent insecticides in various places as reviewed by Cagauan and Arce (1992) and Xiao (1992) (Tables 12, 13).

It is important to note here that besides the statistical significance also the economic significance of the data should be considered and that, with or without the presence of fish, “there are no good data to support any use of insecticides in tropical irrigated rice” (Settle, pers. comm.).

8.3.2 Management of snails

One of the latest pests to hit the rice field in Southeast Asia is the golden apple snail, *Pomacea canaliculata*. This snail, which is of Latin American origin, has invaded most of the rice production areas in Asia (Halwart 1994b). Two species were imported from Florida, USA, in 1980 as a potential food and export crop in the Philippines with a second batch imported from Taiwan in 1984 by two separate private groups (Edra 1991). Seemingly harmless when first introduced, they are now known to be capable of completely devastating rice fields with newly emerging rice plants.

The use of fish as a biological control for snails has been recognized for some time. The review of Coche (1967) lists work done in Uganda, Mozambique and the Congo as early as 1952 to 1957. Then the concern was to control snails that serve as intermediate hosts to *Schistosoma* spp., a trematode that causes schistosomiasis - a debilitating disease in humans that is also known as bilharzia.

To control apple snails, most farmers and government agricultural agencies used chemical molluscicides, mainly organo-tin compounds. Increasing awareness of the hazards posed by organo-tins on humans and livestock led to banning of these in some countries. In the Philippines, the agricultural chemical companies have shifted to metaldehydes after their approval by relevant authorities. Farmers do not find the metaldehydes to be as effective since they are applied in bait form and have to be ingested by the target snails to cause any damage.

Fish are a far better, biological control option. In the Philippines, a three-year program started in 1990 as part of the strategic research in the Asian Rice Farming Systems Network (ARFSN) specifically evaluating the potential of *O. niloticus* and *C. carpio* under laboratory and field (both on-station and on-farm) conditions (Halwart 1994a). Experiments on the feeding response and size-specific predation in a controlled environment suggested that common carp is the preferred biocontrol agent capable of daily consumption rates of up to 1 000 juvenile snails, also feeding on larger snails (Figure 17, Halwart et al. 1998). These results in combination with new data on the snail population ecology resulted in field experiments testing combinations of different snail and fish densities (Figure 18, Halwart 1994a). Results were then further tested for their long-term probability and robustness by developing a snail population dynamics model that identified fish in rice as one of the key determining snail mortality factors (Heidenreich and Halwart 1997; Heidenreich et

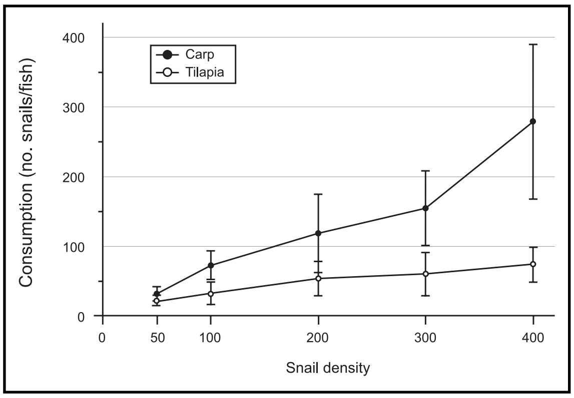

Figure 17. Number of juvenile *Pomacea canaliculata* snails (less than 5 days old) consumed per 24 hours by single fish (*Cyprinus carpio* and *Oreochromis niloticus*) as the initial snail density is varied (Source: Halwart 1994a).

Table 12. Toxicity of different insecticides and herbicides expressed as 48- and 96-hour LC_{50} to *O. niloticus*, *O. mossambicus*, and *C. carassius* tested at the Freshwater Aquaculture Center – Central Luzon State University, Philippines (abridged from Cagauan and Arce 1992).

Pesticide group/ common name	48-hour LC_{50} (ppm of formulated product) and toxicity rank[a]						48-hour LC_{50} (ppm of formulated product)		
	O. niloticus		***O. mossambicus***		***C. carassius***		***O. niloticus***	***O. mossambicus***	***C. carassius***
<u>INSECTICIDES</u>									
Carbamate									
BMPC	5.6 – 6.7	ht	-		28.3	mt	5.4-6.12	-	25.1
Carbaryl	3.10	ht	-		-	-	2.93	-	-
Carbofuran	2.27	ht	2.4	ht	-	-	1.97	1.72	-
MTMC	68.0	mt	52.0	mt	-	-	50.0	46.9	-
MTMC + Phenthoate	9.56	et	-	-	-	-	0.47	-	-
PMC	6.05		6.0[b]	-	34.75	-	-	-	-
PMP	59.0	mt	-	-	3.8	mt	47.1	-	19.6
Organophosphate									
Azinphos ethyl	0.028[b]		0.023[b]		0.009		-	-	0.002
Chlorpyrites	2.0	ht	1.34		-	ht	1.3	1.19	-
Diazinon	45.0	mt	-		40.7		2.2	-	15.2
Methyl parathion	25.7	mt	-		13.4		19.0	-	11.0
Monocrotophos	1.2	ht	47.6		0.31	ht	-	33.10	-
Triazophos	5.6	ht	-		-		-		-
Organochlorine									
Endosulfan	5.8	ht	-		1.3		1.3	-	1.6
Synthetic pyrethroid									
Permethrin	0.75	et	1.3	ht	-		-0.75	-	-
Cypermethrin	0.63	et	-		-		0.63	-	-
<u>HERBICIDES</u>									
2-4-D									
Agroxone (MCPA)									
Rilof (piperophos)	27.5	mt							
Machete (Butachlor)	1,4	ht					1.3		
Modown (bifenox)	149.0	lt			102.0	lt	127.0		102.0
EPTAM D (EPTC)	71.5	mt			49.5	mt	54.4		49.5
Treflan (trifuralin)	308	lt			170.0	lt	225.0		170.0

[a] Ranking of pesticides from Koesomadinata and Djadjaredja (1976) for 48-hour LC_{50}:< 1 = extremely toxic (et); 1 – 10 = highly toxic (ht); 10 to 100 = moderately toxic (mt); and >100 = low toxic

[b] 24-hour LC_{50}

al. 1997). In Indonesia, a preliminary screening pointed at four species with potential for snail control: *C. carpio*, *O. niloticus*, *B. gonionotus*, and *O. mossambicus* (Hendarsih et al. 1994). Among these, *C. carpio* was identified as the best candidate and found to be capable of consuming up to 40 young snails in one day, with the other three species consuming only 84-87% of that number within four days. The findings have been applied in Vietnam where IPM has been identified by FAO as the most suitable approach for snail control with carp being the preferred fish species for biological control (FAO 1998).

8.4 Management of Diseases

The role of fish in a rice field is not limited to controlling the proliferation of weeds, snails, and some insect pests. In China, the Taoyuan County Agricultural Bureau in Hunan province has found that raising *C. idellus* in rice fields controlled rice sheath blight disease (Xiao 1992). The disease

Table 13. Median tolerance limits (TLM) of common carp (*Cyprinus carpio*) to various pesticides (abridged from Xiao 1992).

	Formulated Product	TLM (ppm) 48-hours	Toxicity grade
INSECTICIDE	Trichlorfon	6.2	medium
	Dichlorvos	4.0	medium
	Fenitrothion	4.4	medium
	Malathion	9.0	medium
	Rogor	<40.0	low
	Methyl Parathion	5.0	medium
	Phosmet	5.3	medium
	Phenthoate	2.0	medium
	Baytex	2.0	medium
	Tsumacide	15.3	low
	Landrin	38.1	low
	Bassa	12.6	low
	Etrofolan	4.2	medium
	Chlordimeform	15.2	low
	Rotenone	0.032	high
	Bramaxymil octamoate	0.0	high
BACTERICIDE	EBP	5.0	medium
	IBP	5.1	medium
	Edinphensop	1.3	medium
	Oryzon	6.7	medium
	Plictran	14.6	low
	Thiophanate methyl	11.0	low
	Blasticidin	>40.0	low
	Kasugamycin	100.0	low
	CAMA	10.0	medium
	Phenazine	>10.0	low
	Triram	4.0	medium
HERBICIDE	2,4-D	>40	low
	DMNP	14.0	low
	Propanil	0.4	high
	Nitrofen	2.1	medium
	Benthiocarb	3.6	medium
	Amine methanearsonates	3.7	medium
	GS 13633	0.86	high
	Hedazhuang	34.0	low
	Oradiazon	3.2	medium
	Prometryne	23.5	low
	Glyphosate	119.0	low
	Pentachlorophenol	0.35	high
OTHERS	Zinc Phosphide	80.0	low
	Propargit	1.0	medium
	Lime	140.0	low

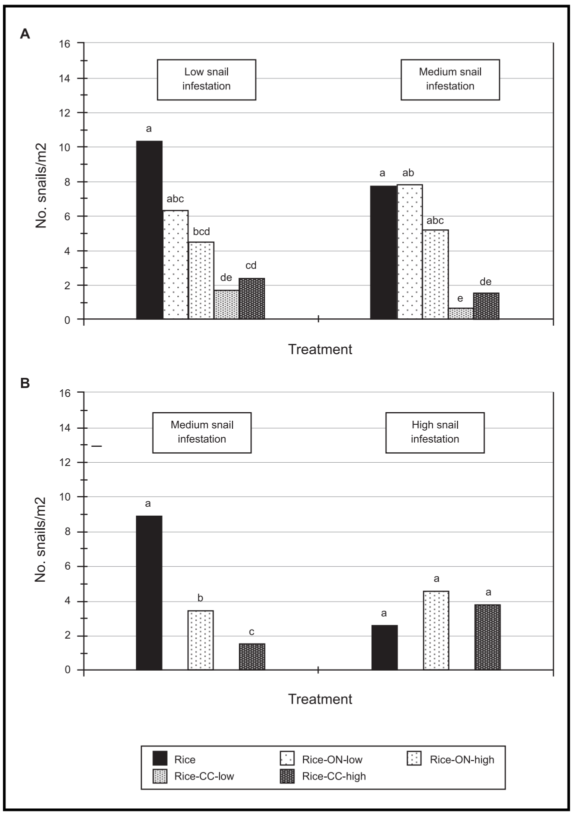

Figure 18. Abundance of live *Pomacea canaliculata* snails collected two days after rice harvest in 50 m^2 plots with pond during the wet season (A) and 200m^2 plots with pond during the dry season (B) at low (0.18 snails·m^2), medium (0.48 snails·m^{2}and high (1.32 snails/m^2) initial snail infestation levels, Muñoz, Nueva Ecija, Philippines. CC = *Cyprinus carpio*, ON = *Oreochromis niloticus*, low = 5000 fish·ha^{-1}, high = 10 000 fish·ha^{-1}. Bars are means of 3 replications. Means within the same snail infestation (low, medium, high) with a common letter are not significantly different at the 5% level by DMRT (Source: Halwart et al. 1998).

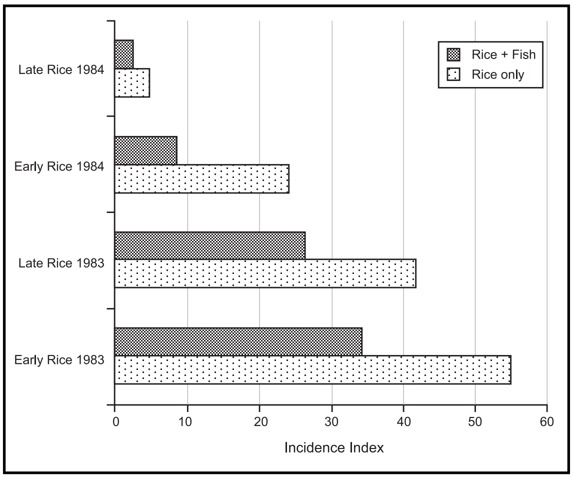

Figure 19. Incidence index of rice sheath blight disease in rice grown with fish and without fish, Tau Yuan Agricultural Bureau, Tao Yuan, China (data Source: Xiao 1992).

incidence index in rice+fish plots ranged from 8.5-34.2 in early rice and 2.4-26.4 in late rice as against 24.1-55.0 and 4.7-41.7 in the controls, respectively (Figure 19). Similar results were observed in Shangyu County, Zhejiang Province (Yu et al. 1995) where disease incidence was lower by 9.9-19.6% in normal depth rice+fish plots.

Yu et al. (1995) offered three mechanisms that enable fish to mitigate the effects of fungal infection. First, the fish stripped the diseased leaves near the bottom of the rice plants that therefore diminished the sources of re-infection in the field. Second, after the bottom leaves of the plants were stripped, improved ventilation and light penetration made the microclimate unfavorable to the fungus. Third, long-term, deepwater conditions prevented any germination of spores and re-infection.

Xiao (1992) reports that *C. idellus* feed directly on the sclerotia (compact masses of fungal hyphae with or without host tissue) of the sheath blight and digest them after 24 hours. Secretions from the fish also appear to slow down the germination of hyphae and reduce infection. However, the fish are effective only when the infection occurs at the water surface. Once the infection spreads upward, away from the water surface, the fish are ineffective.

9. Impact of Rice-Fish Culture

It is the impact of rice-fish that ultimately should determine whether this is a worthwhile endeavor for rice farmers. The impact of rice-fish culture can be measured in many ways, but this section will focus on the direct economic impact followed by its impact on household nutrition, public health and its role in poverty alleviation. Environmental issues then follow.

9.1 Economics of Production

9.1.2 The "bottom line"

In order to assess whether raising fish in the rice field is really worth the extra effort, available comparative cost and returns figures for rice-fish and rice-only farming were examined. Specifically considered are only those cases where both figures were obtained within the same locality during the same period of time. Many of the papers available do have some cost and returns figures for the rice-fish operation, but usually lack the figures for rice only. These are not included in this analysis. As can be seen in Tables 14 and 15, the percentage differences in the net returns vary widely from one country to another and from one year and one place to another within the same country (Yu et al. 1995). However, by and large, the presence of fish had the effect of increasing the net returns.

In Bangladesh the net returns from rice-fish was over 50% greater than that from rice monoculture. The higher net returns were probably due to the lower mean costs of rice cultivation and higher rice yields in addition to the fish yield from integrated farms (Gupta et al. 1998). In China, the increase varied from 45 to 270%. Growing fish was almost three times more profitable than rice alone (Yan et al. 1995a). Lin et al. (1995) related the economic benefits of rice-fish farming to an increase in rice yields and savings in labor and material inputs. Rice yields in rice–fish culture were 8% higher, labor input 19% lower, and material costs were 7% lower (savings in the cost of controlling diseases and pests). Additionally, fish production increased the net income. Indonesian figures show that having two crops of rice-fish and using the rice field for a short intermediate crop or *penyelang* of fish has a 116% higher return than having two crops of rice and leaving the rice field fallow for two months or so. Purba (1998) concluded that the rice-fish system is a profitable technology and that its adoption is likely to increase farm household income, labor absorption, and better liquidity.

In the Philippines, rice-fish farms yielded a 27% higher net return with fish compared to a single crop of rice (Sevilleja 1992). In addition, it has been demonstrated that it is possible to achieve a three-fold increase in profitability of rice farming by culturing fish as well as rice (Fermin 1992; Israel et al. 1994).

Thailand, in contrast to previously mentioned countries, showed lower net returns in the rice-fish fields than in the rice-only fields. The Thai figures indicate that profitability in the rice-fish fields was only 80% that of rice monoculture. Thongpan et al. (1992) attributed this to the high initial investment in rice-fish culture.[18]

A survey of 76 farms in the Mekong Delta of Vietnam (Rothuis et al. 1998a) showed a 16% lower rice yield and a 20% lower overall net return in farms that allocated part of their area to rice-fish culture. Mai et al. (1992) reported that from three farms in the Mekong Delta, the net returns from the rice fields with unfed shrimps was 52% higher than that of rice monoculture and 176% higher in the rice fields where shrimps were fed with rice bran and decomposing animals.

9.1.2 Input analysis

An analysis of what inputs are needed is of importance considering that high input costs will exclude the poorer sections of rural areas. Detailed cost and returns of rice monoculture with the rice-fish system are available for Bangladesh, Indonesia, the Philippines and Vietnam.

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[18] Thongpan et al. (1992) noted that during the dry season of 1985, rice-fish culture had higher returns than rice monoculture, which unfortunately was not presented in detail in the paper. Subsequently, two other farms showed higher profitability in the rice-fish culture during the rainy season of 1985.

Table 14. Summary of cost and returns from rice+fish and rice-only culture, Bangladesh and China. All figures in USD·ha^{-1}·crop^{-1} or USD·ha^{-1}·yr^{-1} as indicated and are rounded to the nearest unit. The last column compares rice+fish against rice only farming in terms of income from rice only, expenses incurred for rice and the net returns.

Rice+Fish System, Year, Period, (Source)	Rice+Fish		Rice Only		% More or (Less)
	Amount	Total	Amount	Total	
BANGLADESH					
Ditch/Sump, *boro* (dry) 1994, (Gupta et al. 1998)[a]					
Rice Income	749		690		8.5%
Fish Income	195				
Rice Expenses	(302)		(326)		(7.4%)
Fish Expenses	(72)				
Net Returns		570		364	56.6%
Ditch/Sump, *aman* (wet) 1993, (Gupta et al. 1998)[a]					
Rice Income	464		444		4.5%
Fish Income	183				
Rice Expenses	(121)		(137)		(11.6%)
Fish Expenses	(31)				
Net Returns		495		307	61.2%
CHINA					
WRDG Grow-out 1987, one crop (Yan et al. 1995)[b]					
Rice Income	559		562		(0.9%)
Fish Income	864				
Rice Expenses	(131)		(158)		(17.1%)
Fish Expenses	(202)				
Net Returns		1 090		404	169.8%
Unsp. Grow-out 1988, one crop, (Lin et al. 1995)					
Net Returns[b]		588		405	45.2%

LEGEND: WRDG – Wide Ridge

a) Original figures in Bangladesh Taka (BDT), converted to USD at the 1994 rate of USD1.00=BDT39.00. Gross rice income not given but was derived using net benefit from rice and rice expenses.

b) Original figures in Chinese Yuan (CNY), converted to USD at the 1987-88 rate of USD1.00=CNY3.72.

Except for Indonesia, all the other cases consistently showed an increase in the overall labor requirement when fish are raised in the rice field, with the amount of increase varying from only 10% to as high as 234%. This was mainly due to the need to prepare the rice field for fish stocking as well as for fish harvesting. However, in some specific activities connected with the rice crop such as fertilizing, weeding and pesticide applications, the presence of fish actually lessened the labor required. Again the amount varies from activity to activity and from one area to another as shown in Table 16.

In terms of fertilizer expense Bangladesh, Indonesia and the Philippines showed from 4% to 14% lower fertilizer costs in rice-fish fields, while Vietnamese figures indicate a 96% increase. The same countries showed significantly lower costs of chemical pesticides in rice-fish farms (44-86%). However, in Vietnam pesticide applications were higher in homesteads practicing rice-fish farm.

9.2 Benefits to Communities

9.2.1 Improved income status of farmers

The immediate beneficiaries of the production of fish and often improved rice yield in rice-fish farming are the farmers who adopt the technology. Although it seems obvious, Ruddle and Prein (1998) have pointedly stated, “the existence of such a relationship has not been demonstrated unequivocally.” However, the fact that many farmers in different countries continue to practice it year after year, even without any government program, would seem to be proof enough of the benefits derived from this type of rice farming.

Models developed using linear programming techniques on a 2.3 ha farm in Guimba, Nueva Ecija, Philippines, show that the adoption of rice-fish farming technology can generate an additional 23% more farm income by raising

Table 15. Summary of cost and returns from rice+fish and rice-only culture, selected Southeast Asian countries. All figures in $USD \cdot ha^{-1} \cdot crop^{-1}$ or $USD \cdot ha^{-1} \cdot yr^{-1}$ as indicated and are rounded to the nearest unit.

Rice+Fish System, Year, Period, (Source)	Rice+Fish		Rice Only		% More or (Less)
	Amount	Total	Amount	Total	
INDONESIA					
Minapadi-Minapadi-Fish vs Rice-Rice-Fallow 1988, one year, (Yunus et al. 1992)[a]					
Rice Income	1 518		1663		(8.7%)
Fish Income	490				
Rice Expenses	(621)		770		(19.4%)
Fish Expenses	(122)				
Net Returns		1244		576	116.0%
PHILIPPINES					
Trench 1986, one crop, (Sevilleja 1992)					
Rice Income	674		700		(3.7%)
Fish Income	126		-		
Total Expenses	(506)		(469)		7.9%
Net Returns		294		231	27.3%
Trench 1986, one crop, (Sevilleja 1992)					
Rice Income	1098			757	45.0%
Fish Income (incl. own consumption)	607				
Rice Expenses	(322)			(390)	(17.4%)
Fish Expenses	(242)				
Net Returns		1141		367	210.9%
Pond Refuge 1991-92, one year, (Israel et al. 1994)[b]					
Rice Income	2077		1579		31.5%
Fish Income (incl. own consumption)	1126				
Total Expenses	(1860)		(1143)		62.7%
Net Returns		1343		436	208.0%
THAILAND					
Unspec. 1984-85, one year, (Thongpan et al. 1992)					
Net Returns		121		160	(24.4%)
VIETNAM					
BW/DWR. 1988, one year, (Mai et al. 1992)					
Net Returns from Rice Monoculture				38	
Net Returns from Rice and Shrimps: fed		105			176.3%
Net Returns from Rice and Shrimps: not fed		58			(34.9%)
Ricefield w/homestead, pond and dike (Rothuis et al. 1998)[c]					
Rice Income	888		1060		(16.2%)
Fish Income	89		6[d]		1383.3%
Income from homestead and dike	175		119		47.1%
Rice Variable Expenses	(544)		(600)		(9.3%)
Fish Variable Expenses	(66)		(3)		2100.0%
Homestead/dike variable expenses	(98)		(91)		7.7%
Total farm fixed cost	(176)		(157)		12.1%
Net Returns		268		334	(19.8)

LEGEND: BW/DWR –Brackishwater Deep Water Rice

a) Extrapolated to 1 ha from weighted average of 6 farms of 0.35-1.0 ha for rice-rice-fallow and 0.5 -1.5 ha for minapadi-minapadi-fish.

b) Original figures in Philippine Peso (PHP), converted to USD at 1991 rate of USD1.00= PHP27.48.

c) Original figures in Vietnam Dong (VND), converted to USD1.00=VND11 000 as given by authors .

d) Even farmers not adopting rice-fish farming maintained a small fishpond accounting for the fish.

Table 16. Relative cost of labor and material inputs in rice+fish culture and rice only culture.

	Bangladesh 1994[a] (Gupta et al. 1998)			Indonesia 1988 (Yunus et al. 1992)			Philippines,1991-92, (based on Israel et al 1994)[c]			Vietnam 1994-95[e] (Rothuis et al. 1998)		
	Rice + Fish	Rice Only	% more (less)	Rice + Fish	Rice Only	% more (less)	Rice + Fish	Rice Only	% more (less)	Rice + Fish	Rice Only	% more (less)
GROSS RETURNS	943.56	689.77	36.8%	2 087.54	1 663.02	25.5%	3 202.70	1 579.37	102.8%	1 152.55	1 186.00	(2.8%)
Rice	748.59	689.77	8.5%	1 518.24	1 663.02	(8.7%)	2 077.03	1 579.37	31.5%	888.45	1 060.18	(16.2%)
Fish	194.97[b]			569.30			1 125.67			89.00	6.45	1,28.9%
Others										175	119	46.7%
COSTS	374.4	325.7	15.0%	743.55	770.21	(3.5%)	1 701.17	1 095.20	55.3%			
Labor	158.28	153.34	3.2%	449.11	528.72	(15.1%)	720.93	404.57	94.3%	299.80	261.28	14.7%
Dikes, Refuge & Repairs	13.92						43.87	7.79	463.5%			
Land Preperation	35.90	35.44	1.3%	54.18	90.65	(40.2%)	93.28	93.28	0.0%			
Seeding (Pulling/ Handling)				7.01	9.53	(26.4%)	27.97	27.08	3.3%			
Transplanting	32.13	32.49	(1.1%)	31.92	40.79	(21.8%)	77.98[d]	54.20[d]	43.9%			
Fertilizing				5.78	11.20	(48.4%)	14.71[d]	13.64[d]	7.8%			
Pest eradication				10.31	20.30	(49.2%)	-	-				
Weeding	23.00	32.54	(29.3%)	12.88	18.75	(31.3%)	-	-				
Rice Harvesting	53.33	52.87	0.9%	303.37	337.49	(10.1%)	251.68	208.58	20.7%			
Stocking				1.48			3.74					
Feeding, other fish tanks				16.27			34.45					
Fish Harvesting				5.93			173.24					
Irrigation & Water Management	6.85						158.36	48.02	229.8%	63.17	36.00	75.5%
Inputs				218.48	156.89	39.3%	607.76	421.20	44.3%			
Rice Seed	17.05	19.23	(11.3%)	18.76	17.57	6.8%	93.19	95.61	(2.5%)	72.97	66.63	9.5%
Fertilizer	60.31	70.38	(14.3%)	86.53	90.22	(4.1%)	149.32	164.87	(9.4%)	197.02	100.34	96.4%
Chemicals	0.97	7.10	(86.3%)	27.19	49.11	(44.6%)	15.11	53.45	(71.7%)	33.09	14.44	129.1%
Fingerlings	44.08	-		78.47			120.09			45.66	-	
Feeds	7.21	-		7.53			56.73			23.87	-	
Fuel							173.32	107.27	61.6%			
Fixed Costs	79.62	75.62	5.3%	75.95	84.60		372.49	269.43				
NET RETURNS	569.21	364.10	56.3%	1 343.99	892.81	50.5%	1 343.16	436.14	208.0%			

a) Dry season (boro) crop. Original currency in Bangladesh taka (BDT), converted at USD1.00 = BDT 39.
b) Fish yield does not include wild fish.
c) Constructed using farm by farm data from Israel et al (1994), original currency in Philippine Peso (PHP) converted at the 1991 rate of USD1.00 = PHP27.48
d) Transplanting includes labor for weeding and fertilizing includes labor for pesticide application.
e) One-year operation of one-hectare farm w/ rice field, homestead, dike and pond based on double rice crop and one fish crop. The data entered in this table is not complete and do not add up as they do for the other countries since the manner of presentation in the original paper did not lend itself to reformatting. Original figures were in Vietnamese dong (VND) and were converted at the rate of USD1=VND11 000. The difference between the gross returns is reported to be not statistically significant.

fish as well in 0.5 ha. This increases to 91% if the entire 2.3 ha area is stocked with fish, even if rice production remains constant and farm requirements for cash and labor increased by 22% and 17%, respectively (Ahmed et al. 1992).

One indication that fish farming in rice fields must be satisfactory (economically or otherwise) from the farmers' perspective is that in many cases farmers on their own continue or even expand the extent of their rice-fish farms after having tried the technology. For example, Zambian farmers wanted to continue with rice-fish farming although researchers had found it to be uneconomical (Nilsson and Blariaux 1994). In Northeast Thailand, the total rice field area stocked with fish increased each year from 1985 to 1987 in spite of a dismal showing the first year (Thongpan et al. 1992). It has been pointed out that nutritional benefits and lowered risk of production may provide strong motivation for rice farmers to diversify and that rice-fish farming can be "profitable" in many ways including from social, environmental, or ecological point of views (Halwart 1999).

9.2.2 Improved nutrition

One benefit that is often assumed, but never supported by solid evidence, is that farmers who culture fish in their rice fields have improved nutrition. Villadolid and Acosta (1954) and Coche (1967) and other writers postulated that fish could prevent protein deficiency and contribute to the improved socioeconomic welfare of populations. Yet in the case of rice-fish farming there are no figures available as to how much the caloric and protein intake or the per caput fish consumption of farmer families have been increased by the availability of fish once these are grown in their own rice fields. For example, it is estimated that home consumption accounts for 35% of the production in Northeast Thailand, but no absolute figure was given (Mackay 1992). To complicate the matter, direct consumption of the animals cultivated depends a great deal on the market value of the product and the economic status of the farmer.

In the Philippines, and most likely elsewhere, farmers may be less inclined to have the "additional burden" of raising fish if its main purpose is to improve their own nutrition. Farmers will likely culture fish if they believe they can earn extra cash out of it beyond what they are already earning from rice. Horstkotte-Wesseler (1999) found no reduction in food expenses in households practicing rice-fish culture as all fish of marketable size produced were sold and none consumed in the household. Income augmentation was the most frequent reason provided for engaging in rice-fish, additional food only ranked third (Saturno 1994). In Bangladesh, it was pointed out that extra income was the most appreciated benefit from growing fish (70%) followed by "increased food for the family" (59%) (Gupta et al. 1998).

Improvements of a farming household's nutrition as a result of culturing fish in the rice fields may just be an incidental and perhaps even indirect effect, such as being able to buy meat or chicken as a result of the extra cash earned from fish. The main benefit of rice-fish farming is often seen as providing an opportunity to earn cash.

Improvement in the local community's nutrition has been cited as one of the benefits of rice-fish farming. With greater availability of fish, the local population of a rice farming community will have easy access to fish at affordable prices. However, in a free market the farmer may opt to sell the fish to a trader at a higher price than what the neighbors can afford. The trader in turn may opt to bring the fish to the nearest urban center where prices are higher. This is a common situation in most fishing communities in the Philippines where fish can be difficult to find in the local market having been siphoned off to the cities.

Nevertheless, particularly in more remote areas and where the mixed forms of capture and culture are prevalent, it is estimated that fish and other aquatic organisms from rice fields provide a very important component of the daily diet, hence also the term "rice-fish societies" (Demaine and Halwart 2001). The nutritional contribution extends from micronutrients and proteins to essential fatty acids that are needed for visual and brain development. Recognizing this, the 20th Session of the International Rice Commission recommended its member countries to pay increased attention to the nutritional value of fish and other aquatic organisms from rice fields (FAO 2002; Halwart 2003a). A recent FAO/IUCN study in Lao PDR confirms the urgent need for further focus on this issue (Meusch et al. 2003).

9.2.3 Public health

There are two public health vectors against which fish have been employed: mosquitoes and snails.

Mosquitoes are known carriers of malaria and dengue fever. Certain species of freshwater snails serve as hosts to trematodes (*Schistosoma* spp.) that cause schistosomiasis should it enter the human bloodstream. A third aspect is that rice-fish culture may reduce the use of agricultural chemicals that pose a health hazard to humans. In some areas, where there is a tradition of using nightsoil and/or there is a lack of latrines, human infections with fish borne trematodes may be an issue when fish from rice fields are eaten raw or semi-preserved.

Field surveys in China indicate that mosquito larvae densities in rice fields with fish were only 12 000 · ha^{-1} as against 36 000 · ha^{-1} in rice fields without fish (Wang and Ni 1995). In other studies mosquito larvae were observed in only one of nine rice fields stocked with fish, being completely absent in the other eight, whereas in other rice fields not stocked with fish, the density of mosquito larvae ranged from 32 000 to 128 000 · ha^{-1}. In Indonesia, fish were found to be even more effective in controlling mosquitoes than DDT. After five years of fish culture in rice fields, malaria cases decreased from 16.5% to 0.2% in a highly endemic area for malaria (Nalim 1994). In a control area using DDT the malaria prevalence remained steady at 3.4% during the same period.

The effect of fish on the schistosoma-carrying snails is less clear. As reviewed by Coche (1967) fish were tested in the past for that purpose in many parts of Africa where schistosoma was endemic. At an experimental level, good results were obtained when the *Louisiana* red swamp crayfish was introduced into small rain-filled quarry pits to control the schistosome-transmitting *Biomphalaria* and *Bulinus* snails in Kenya. Later work on fish as snail predators has focused more on the golden apple snail as was discussed in the section on rice pests, and for which purpose it has been found effective (Halwart 1994a; Halwart et al. 1998; Hendarsih et al. 1994; FAO 1998). In countries such as China, black carp (*Mylopharyngodon piceus*) is used to control snails that are intermediate hosts in parasite transmission. In Katanga, the majority of snails in rice fields were controlled by *Haplochromis mellandi* and *Tilapia melanopleura* stocked at 200 fish · ha^{-1} and 300 fish · ha^{-1}, respectively. Halwart (2001) concludes that well-maintained aquaculture operations contribute, often significantly, to the control of insects and snails of agricultural and medical importance, and that integrated management programes should be pursued to keep vectors and pests at levels where they do not cause significant problems.

Often overlooked is the fact that fish in the rice fields can reduce the use of chemical pesticides. Despite the fact that some pesticides are considered safe to use in rice-fish farming due to their low toxicity, low tendency to bio-accumulation, and short half-life, pesticides are still poisons and may be carcinogenic or harmful in other ways. Their use and misuse is a serious public health issue that may become more serious than mosquitoes and snails. Fish are potentially a good herbicide and insecticide and stocking can greatly reduce, if not completely eliminate, the need for using chemical pesticides. The presence of fish discourages farmers from applying pesticides (Saturno 1994). The reduction or elimination of the need to apply chemicals cannot but result in an environment that is safer and healthier for the people.

9.2.4 Social impact

It seems far-fetched that stocking fish in rice fields can have a significant impact on the society as a whole, particularly so with isolated cases of technology adoption by one or a few farmers widely dispersed. However, when there is a large-scale adoption involving an entire community the social impact can be quite profound.

The use of fallow rice lands for fish culture by landless farmers in Indonesia as described by Ardiwinata (1957) is one such case. The situation prevailing in Indonesia in the past was that landless tenants were allowed to use the rice fields for fish culture during the fallow season, giving birth to the *palawija* system. Nowadays, the use of the rice fields for fish production during the fallow season is not limited to landless tenants, but involves fish breeders requiring a larger area for raising fingerlings (Koesoemadinata and Costa-Pierce 1992; Fagi et al. 1992). In real-estate development jargon such a scheme is called time-sharing, an efficient use of a resource giving a chance for the landless to have access to land, however temporary.

Although the Indonesian example may be unique, in general adoption of rice-fish farming should result in job creation. Physical modifications of rice fields to accommodate and harvest fish require extra labor. In the Philippines ancillary activities connected to tilapia fingerling production are:

- diking and excavation;
- making hapa-nets, harvesting seines and other fish culture accessories;
- renting out water pumps, harvesting nets, oxygen tanks, etc.;
- repair of pumps and making steel hoops for scoopnets, etc.;
- harvesting, sorting and packing of fingerlings; and
- transport of fingerlings.

Each type of activity is done by a different person. This makes it possible to operate a tilapia hatchery without incurring a large capital cost or having a wide range of equipment or maintaining more personnel than necessary. As none of these aspects have been quantified and documented, there is little good information available on the amount of labor generated.

9.3 Impact on the Environment

The impact of rice farming on the environment, including its contribution to the greenhouse effect, should be a matter of concern to everyone. There is no doubt that the development of rice lands has resulted in the loss of natural wetlands and marshlands, although this made a difference between widespread famine and food sufficiency in many parts of the world. This section, however, will only examine what impact the introduction of fish may have on the ecosystem of an existing rice field.

9.3.1 Biodiversity

A rice field is known to be the habitat of a diverse assemblage of species (Heckman 1979; Balzer et al. 2002). Intensification of rice cultivation with an associated increase in chemical pesticide use is reducing this diversity (Fernando et al. 1979). Since rice-fish farming often reduces the need to use chemicals for pest control, this assists in preserving a diverse rice field biota. Utilizing the existing - native - species for rice-fish culture serves to actively preserve the biodiversity.

9.3.2 Water resources

With fish in the rice field, a greater water depth has to be maintained and more water may be required, an issue raised half a century ago by Schuster (1955). Even without fish, rice farming consumes large volumes of water. For rice culture in general, Singh et al. (1980) and Sevilleja et al. (1992) estimated that a crop needs a minimum of 1 000 to 1 500 mm of water, respectively. If a hectare of rice field produces 10 mt of rice, it still takes from 1 to 1.5 m^3 of water to produce 1 kg of paddy.

Fish are a non-consumptive user of water, and while they can degrade the water they do not use it up. If cleaned, the same water can be returned and reused by the fish. The increased water use is due to percolation and seepage (P&S) and leakage (L), which increase with rice-fish culture due to the deeper water maintained, a purely physical process that takes place with or without the fish. Sevilleja et al. (1992) estimated that the water requirement for rice culture was 1 662 mm while rice-fish culture required up to 2 100 mm, or 26% more than rice monoculture. The main water losses are attributable to P&S (67%), followed by L (21%). Thorough puddling during land preparation, good maintenance of the dikes and proper sealing of inlets and outlets may reduce the losses.

9.3.3 Sustainability

Wet rice cultivation has been practiced for at least 4 000 years, and its long history indicates that traditional rice farming is basically sustainable. What is less certain is whether the dramatic increases of rice production made possible by the "green revolution" are sustainable (Greenland 1997). Global warming, sea level rise, increased ultraviolet radiation and even availability of water are all expected to have an adverse impact on rice production. However, such scenarios are far beyond the level and scope of this report, and for the foreseeable future it can be assumed that rice farming will continue. Further, it seems likely that the culture of fish in rice fields can enhance the sustainability of rice farming, since indications are that the presence of fish makes the rice field ecosystem more balanced and stable. With fish removing the weeds and reducing the insect pest population to tolerable levels, the poisoning of the water and soil may be curtailed.

9.4 Participation of Women

In most of the rice-producing countries of Asia, women are already an integral part of the farm labor force. The integration of fish culture into the rice farming activity will likely expand women's participation further. There are no socioeconomic data quantifying possible involvement of women in rice-fish farming activities but as Dehadrai (1992) has amply stated, any "projected new opportunities for women in rice-fish farming emanate largely from the known and well documented involvement of women in the management of rice in Asia." A beneficial aspect may be that the presence of fish in the rice fields could save precious time that women and children otherwise spend fishing in other areas, although this effect is somewhat counterbalanced by the extra work needed for the rice-fish management.

9.5 Macro-Economic Impact

There are three macro-economic issues on which the widespread adoption of rice-fish farming technology could impact: food security, employment generation, and national income. However, such discussions will be in the realm of speculation since most countries do not have separate statistics on rice-fish farming areas nor rice and fish yields in such areas.

Speculations, however, indicate that the potential impact is tremendous. If 5% of the irrigated rice lands in the Philippines were stocked with fish, the production would increase by 29 000 t worth US$ 35 million and provide 5 900 t of protein (Ahmed et al. 1992). Cai et al. (1995a) estimated that if 10% of the rice fields south of the Huai He River, China, were used, the commercial fish yield would be 346 000 t at a yield of 300 kg/ha, and 5 billion full-size fingerlings. With such production potential the ecological and economic benefits would be considerable.

Coche (1967) summed it up very well by saying that fish culture in rice fields is technically an almost ideal method of land use, combining the production of both vegetal and animal proteins. Its further development is important, as it may contribute to a guarantee of the world food supply. Widespread adoption of rice-fish farming as a strategy to substantially narrow the gap between the protein supply and demand is a potential option for any major rice-producing country. All it requires is the political will to push through with it.

10. Experiences of Various Countries

As far as can be ascertained from the available literature, rice-fish farming is still practiced in quite a few countries as shown in Figure 20. There are no hard statistics on the total extent of rice-fish farming globally but estimates for the major countries are available (Table 17). The world's rice-fish farms are concentrated within South Asia, East Asia and Southeast Asia but there are also some notable developments in Africa. This chapter mainly provides a historical perspective and reports on the current status in major regions.

10.1 East Asia

China

China, with 27.4 million ha of rice land, is second only to India in terms of hectarage but is first in terms of rice production with about 166 million t.[19] It is the world's largest aquaculture producer with an inland production of 28 million t,[20] and rice-fish culture has always been given a strong emphasis in China. It also has the oldest archaeological and documentary evidence for rice-fish farming.

However, it was not until after the founding of the People's Republic of China in 1949 that rice-fish culture developed quickly in the whole country. In 1954 it was proposed that development of rice-fish culture should be spread across the country (Cai et al. 1995a), and by 1959, the rice-fish culture area had expanded to 666 000 ha. From the early 1960s to the mid-1970s there was a temporary decline in rice-fish farming. This was attributed to two developments: first, the intensification of rice production that brought with it the large-scale application of chemical inputs; and second, the ten-year Cultural Revolution (1965-75) during which time the raising fish was considered a bourgeois way of making money and was officially discouraged.

Improved rice varieties, use of less toxic chemicals and political changes (production-contract or production responsibility system) reversed the earlier trends of the 1960s and 1970s. The new

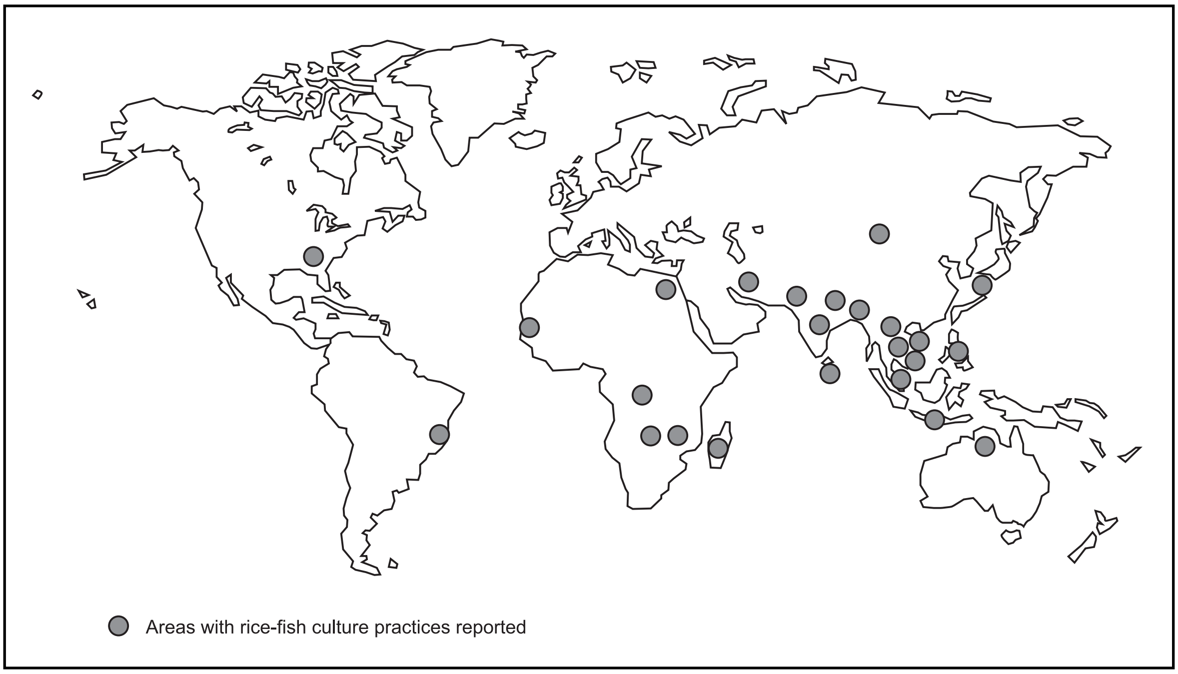

Figure 20. Map of the world showing areas where rice-fish and/or rice-crustacean farming is practiced.

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[19] FAOSTAT data (2003).

[20] FAO FISHSTAT data (2002), excluding aquatic plants.

Table 17. Distribution of rice and rice-fish area, by environment (Halwart 1999).

Country	Rice					Rice-fish
	Total	Irrigated	Rainfed Lowland	Floodprone	Upland	
	('000 ha)					('000 ha)
Bangladesh	10 245	22	47	23	8	?
Cambodia	1 910	8	48	42	2	?
P.R. China	33 019	93	5	-	2	1204.9
Egypt	462	100	-	-	-	172.8
India	42 308	45	33	7	15	?
Indonesia	10 282	72	7	10	11	138.3
Korea, Rep.	1208	91	8	-	1	0.1
Lao PDR	557	2	61	-	37	?
Madagascar	1 140	10	74	2	14	13.4 (highlands)
Malaysia	691	66	21	1	12	?
Philippines	3 425	61	35	2	2	?
Sri Lanka	791	37	53	3	7	?
Thailand	9 271	7	86	7	1	25.5 (culture) 2966.7 (capture)
Vietnam	6 303	53	28	11	8	40.0 (Mekong delta)

system allowed individual families, rather than the commune, to become the main production units. In addition, the rapid development of aquaculture required a large supply of fry and fingerlings. This demand was partly met by fingerling production in rice fields.

In 1983, the Ministry of Agriculture, Animal Husbandry and Fisheries (now the Ministry of Agriculture) organized the First National Rice Fish Culture Workshop. The workshop resulted in the establishment of a large coordination group for Eastern China to popularize rice-fish farming techniques. Also various other provinces, autonomous regions and municipalities undertook such measures in line with local conditions. As a result, by 1996 China had 1.2 million ha of rice-fish farms producing 377 000 t of fish (Halwart 1999).

Thus it can be seen that in China rice-fish farming is promoted actively as a viable option for rice production. It is part of the program not only of fishery institutions, but also of agencies involved in rice production. In addition, it receives considerable support at the ministerial level of government.

Japan

Rice-fish farming appears to be of minor importance in Japan and there is not much literature on the subject. After reaching a peak production of 3 400 t in 1943 due to war-time food production subsidies, carp production in rice fields decreased to only 1 000 t during the 1950s. In 1954 only 1% of Japan's 3 million ha of rice land was used for carp culture (Kuronoma 1980) and it is no longer practiced on a significant scale, if at all (Pillay 1990).

Korea

In Korea, rice-fish farming started only in the 1950s and never spread widely because the fish supply from inland waters was sufficient to meet the limited demand for freshwater fish (Kim et al. 1992). Inland production accounted for only 1.7% of the total fish production of 3.3 million t in 1987. As of 1989 only 95 ha of rice fields were being used for fish culture, and only for the growing the most popular species of loach (*Misgurnus anguillicaudatus*).

10.2 Southeast Asia

Indonesia

Rice-fish farming is believed to have been practiced in the Ciamis area of West Java, Indonesia, even before 1860 although its popularization apparently started only in the 1870s. Ardiwinata (1957) attributed the expansion of fish culture in rice fields to the profound changes in the governing system during the Preanger regency in West Java in 1872, during which the possession of rice fields was made hereditary. The pressure on the arable land by the growing population caused the rental rates to go up. Tenants started to utilize their fields by stocking fish, generally common carp, or by raising other crops. Fish culture was popular because the capital required was minimal, and the landowners did not expect a share of the fish. This practice is what is called *palawija* or fallow-season crop.

The spread of *palawija* outside its point of origin in Java is attributed to the Dutch administrators who promoted the concept. By the 1950s some 50 000 ha of rice land were already producing fish. The development of irrigation systems also contributed to the expansion of the area used for rice-fish farming. The average area of rice-fish farming increased steadily after Indonesia became independent in 1947 and rice-fish farms covered 72 650 ha in 1974, but declined to less than 49 000 in 1977. The decline was attributed, ironically, to the government's rice intensification program (Koesoemadinata and Costa-Pierce 1992). However, the surging demand for carp fingerlings brought about by the proliferation of fish cages in dams and reservoirs stimulated expansion once again. The area utilized reached an all time high of 138 000 ha in 1982, but declined to 94 000 ha in 1985.

Recent reports indicate that rice-fish farming is on the upswing. The 1995 figures from the Directorate General of Fisheries indicate a total area of over 138 000 ha. The resurgence has been attributed to a drastic change in rice production practices in 1986 when integrated pest management (IPM) was declared the official national pest control strategy. At present rice-fish farming is practiced in 17 out of 27 provinces in Indonesia. In summary, the development of rice-fish farming can be attributed to landless tenants who wanted an extra income during the fallow season for rice. The government's rice intensification program, promoting heavy use of chemical pesticides, was the major reason for its decline in the early to mid-1970s. Its growth at present has been attributed to the increased demand for fingerlings to stock fish cages, which makes it a purely market-led development.

Thailand

Integrated rice-fish farming is believed to have been practiced for more than 200 years in Thailand, particularly in the Northeast where it was dependent upon capturing wild fish for stocking the rice fields. It was later promoted by the Department of Fisheries (DOF) and expanded into the Central Plains. The provision of seed fish and technology helped in popularizing the concept. Rice yields in rice-fish farms in the 1950s increased by 25-30% and the fish yields ranged from 137 to 304 $kg \cdot ha^{-1} \cdot crop^{-1}$ (Pongsuwana 1962). As a measure of the importance given to rice-fish farming, the DOF established a Center for Rice-Fish Farming Research in Chainat in the Central Plains in 1968. However, during the 1970s, Thailand, like the rest of Asia, introduced the HYVs of rice and with it the increased use of chemical pesticides. This resulted in the near collapse of rice-fish farming in the Central Plains as farmers either separated their rice and fish operations or stopped growing fish altogether. In 1974 the research center in Chainat was closed.

However, rice-fish farming did not completely vanish and in recent years it has recovered, particularly in the Central Plains, North and Northeast Regions. In 1983 rice field culture fisheries was practiced on 2 820 ha mainly in the Central, North, and Northeast Provinces. This grew to 23 900 ha in 1988 and was further expanded to 25 500 ha in 1992. Such a steep increase resulted from a general decrease in the availability of wild fish made worse by the occurrence of the ulcerative disease syndrome in wild fish stock . Fedoruk and Leelapatra (1992) attributed the recovery to more discriminate use of HYV; the emergence of pesticides that when properly applied are not toxic to fish; the growing perception of the economic benefits of rice-fish farming, and its promotion in special projects assisting disadvantaged farmers, among other factors.

Little et al. (1996) concluded that the development of rice-fish systems is unlikely to be homogeneous in the Northeast Region. The high expectations of farming communities is thought to be a major constraint to the wider adoption of rice-fish systems where off-farm employment was the norm as the major means of livelihood until the economic crisis in mid-1997. The increasing frequency of directly broadcasting rice seeds and using machines for field preparation are signs of the growing labor shortage. The shortage may favor the development of more easily managed pond culture rather than the more laborious rice-fish system. On the other hand, adoption of rice-fish systems in the Northeast Region may be biased towards those who are betteroff and have access to labor and other resources.

Malaysia

In Malaysia, from where reports on the practice of rice-fish farming appeared as early as 1928, the rice fields have always been an important source of freshwater fish. Before the 1970s when farms still practiced single-cropping, integrated rice-fish farms were the major suppliers of freshwater fish, especially for snakeskin gouramy (*T. pectoralis*), catfish (*Clarias macrocephalus*), and snakehead (*Channa striata*). Fish production from rice field started to decline with the introduction of the double-cropping system and with it the widespread use of pesticides and herbicides (Ali 1990).

Vietnam

Vietnam has a strong tradition of integrating aquaculture with agriculture. The Vietnamese system involves the production of livestock, vegetables, and fish in a family farm and does not necessarily involve rice. While fish, shrimps and other aquatic organisms were traditionally caught in the rice fields, these were reported to have become scarce ever since chemical pesticides started to be used (Mai et al. 1992). Le (1999) reports five common rice-fish culture systems being practiced in Vietnam, but gives no figures on the area involved. The five systems are fish-cum-rice for nursery and growout, fish-cum-rice for growout only, shrimp-cum-rice, fish/rice rotation and shrimp/rice rotation.

The Philippines

In the Philippines, fish are traditionally allowed to enter the rice fields with the irrigation water and are later harvested with the rice. The earliest mention of stocking fish in a rice field in the Philippines was made in 1954 (Villadolid and Acosta 1954), but it was not until 1974 when rice-fish farming became part of a research program of Central Luzon State University (CLSU). In spite of the lower rice yields (on average 3.8%), in 1979 the government proceeded to promote rice-fish farming nationwide. The decision was based on the results of the economic analysis that even with a reduced rice production, the farmer would still be economically ahead due to the additional income from the fish. After a peak of 1 397 ha involving 2 284 farms in 1982 the program was discontinued in 1986. At that time it covered only 185 ha (Sevilleja 1992) despite the fact that the average production of rice from rice-fish farms was above the national average.

Sevilleja (1992) did not offer any explanation for the sudden drop in the participation by 1983; however records show that 1983 was one of the worst El Niño years in recent history and the drought badly affected agriculture (Yap 1998). The year 1983 also marked the start of political turmoil and relative politico-economic stability did not return until 1990. The failure of the rice-fish promotion in the Philippines should also be viewed against the political milieu. In 1999, a more modest rice-fish program was launched.

10.3 South Asia

Rice-fish farming is known to have been practiced in India, Bangladesh and Sri Lanka and much of the history, current practice and potential is highlighted by Fernando and Halwart (2001) in their paper on fish farming in irrigation systems with special reference to Sri Lanka.

India

Having the world's largest area devoted to rice cultivation at 42 million ha as of 1994, India produces a considerable amount of fish from its rice fields. A report on the status of rice-fish farming in India (Ghosh 1992) indicates that India has rice-fish farms covering 2 million ha, which is the largest reported area for rice-fish culture for a single country. Rice-fish farming is considered an age-old tradition in the states of West Bengal and Kerala, but it is limited to capture systems in the Ganges and Brahmaputra plains.

The practice cuts across different ecosystems, from the terraced rice fields in the hilly terrain in the north to coastal *pokhali* plots and deepwater rice fields. In between are the mountain valley plots of northeastern India and rainfed or irrigated lowland rice fields scattered all over India. The species involved are just as diverse with over 30 species of finfish and some 16 species of shrimps listed as being cultured in Indian rice fields. Most of the non-carp species and penaeid shrimp species are from natural stocks entering the rice field with the flood waters. Production rates are varied, ranging from 3 $\mathrm{kg \cdot ha^{-1} \cdot year^{-1}}$ in the deepwater rice plots relying on natural stock of mixed species to over 2 $\mathrm{t \cdot ha^{-1} \cdot year^{-1}}$ of Tiger shrimps (*P. monodon*) in shallow brackish water rice fields (Ghosh 1992).

Bangladesh

Farmers in Bangladesh have been harvesting fish from their rice fields for a very long time.

The description of the traditional practice in Bangladesh that follows came from Dewan (1992). Farmers construct ponds of different sizes in low-lying areas of the field and when the ponds and rice fields are full of water during the monsoon, carp fry are released, following no specific stocking density. The small ponds may be provided with brush shelters, but no fertilizers or feed are applied. The fish are harvested over a period extending from the time the rice is harvested in November-December up to March. In the coastal areas, marine shrimps such as the various penaeids including *P. monodon* may also be cultured. The traditional *bheri* system is used wherein the rice fields are enclosed by small embankments complete with inlet channels and sluice gates. Fields vary in size from 3 to 50 ha. Both rotational and concurrent systems are practiced. Occasionally, the freshwater prawn (*M. rosenbergii*) may also be cultured. Prawn fry gathered from nearby rivers are stocked after the monsoon rains have washed out the salinity from the rice fields.

Intensive studies and surveys undertaken from 1992 to 1995 in Bangladesh showed improvement in income and food availability for most of the respondents to the extent that 89% of the farmers involved planned to continue with the practice (Gupta et al. 1998). CARE-Bangladesh promoted rice-fish culture in all its projects as an integral part of its IPM strategy (Nandeesha and Chapman 1999).

Bangladesh is one of the few countries actively promoting rice-fish farming and pursuing a vigorous research and development program. NGOs in Bangladesh are likewise showing increasing interest in rice-fish farming. Among the more successful NGO efforts was the Noakhali Rural Development Program in 1989 which used the rotational system to produce from 223 to 700 $kg \cdot ha^{-1}$ of mixed species of fish in 50 fields planted with local rice varieties (Haroon et al. 1992). More recently, CARE has become the most active NGO involved in rice-fish farming.

Thousands of farmers in Bangladesh have experimented with rice-fish culture and have developed practices to suit their own farming systems. Both table fish and fingerlings are being produced with farmers generally concentrating on fish seed during the dry season, which is an irrigated crop. The adoption rate among the project participants has been in the range of 10-40% depending on the area and sex of the participant. Initially the adoption rate was lower among females, but the activity is reported to be gaining popularity among both male and female groups. Increased income and fish consumption have been noted among families adopting rice-fish culture in Bangladesh.

10.4 Australia

A large commercial rice grower in Newcastle, New South Wales is stocking common carp in rice fields on a trial basis. The intention is to eventually stock 5 000 ha with common carp on a concurrent basis with rice. The fish produced will be used as raw materials for pet food (personal communication, Mr. Jonathan Nacario, Consultant, 12 October 1999).

10.5 Africa, Middle East and West Asia

Apart from Egypt, Africa has 10 rice producing countries with a total rice land area of 6.8 million ha. Nigeria has the largest rice area with 1.7 million ha, followed by Madagascar and Guinea with 1.2 million ha and 1.1 million ha, respectively. In terms of rice production Nigeria is first with 3.8 million t, followed by Madagascar with 2.36 million t.

Madagascar

The earliest report on rice-fish culture in Africa comes from Madagascar. As early as 1928. Legendre (cited in FAO 1957) reported on the practice in Madagascar on the culture of *Paratilapia polleni*, *Carassius auratus* and *Cyprinus carpio* in rice fields. This was followed by another report in 1938 on poultry-raising and fish culture in rice fields. Based on the report of Coche (1967), the level of technology in Madagascar at that time appears to have approximated that of Asia, although stocking was lighter. Both concurrent and rotational systems relying on entry of natural fish stock were practiced. In 1952 the government initiated a program to promote fish culture in fishponds and rice fields. Local capacity in the mass production of fingerlings was developed in 1972. Only in 1979 was sufficient progress made for the government to promote rice-fish culture. Fingerling supply remained a major constraint until 1985 when the government promoted private sector participation in fingerling production. By the end of the 1980s it was realized that without continued external assistance the government would be unable to sustain the operation (Van den Berg 1996). An average yield of 80 kg · ha^{-1} indicates that culture techniques at the farm level still need to be improved (Randriamiarana et al. 1995).

A country with almost 900 000 ha of rice fields does have a great potential for rice-fish farming, as about 150 000 ha could be suitable for rice-fish farming. A potential annual production of 300 000 t of edible fish has been projected from the said areas. Rice-fish culture in Madagascar was significant enough to be mentioned in a country study done by the US Library of Congress (Metz 1994).

Malawi

Farmers in Malawi are just beginning to grow rice and fish together as well as fish and vegetables. Although not specifically mentioned, the fish involved are apparently tilapia, where *O. shiranus* and/or *T. rendalii* are reportedly the principal species in the country.

Zambia

Rice-fish culture trials have been reported for Zambia by Coche (1967) but failed to take off. In 1992-93, FAO again introduced the concept during the implementation of the Aquaculture for Local Community Development Programme (ALCOM). Although the project was discontinued when economic analysis showed that income from the fish and the additional rice harvested failed to compensate for the additional cost of culturing fish, many farmers continued with the practice on their own (Nilsson and Blariaux 1994).

Senegal

In Senegal, low-land farmers have resorted to integrating fish culture with rice farming due to environmental changes that endangered their rice farms (Diallo 1998). Seawater encroaching on their rain-fed coastal rice fields forced them to build fishponds to prevent tidal waters from inundating their rice fields. In the process they also produce fish.

Other African Countries

Congo-Katanga (now known as Shaba province of the Republic of Zaire) and Rhodesia (now Zimbabwe), Ivory Coast, Gabon, Liberia and Mali and Benin are reported to have conducted rice-fish culture trials (Coche 1967; Nzamujo 1995; Vincke 1995). More recent activities for West Africa have been documented by Moehl et al. (2001). Integrated aquaculture trials have been limited to fish with only livestock in both Cameroon (Breine et al. 1995) and Rwanda (Verheust et al. 1995).

Egypt

Egypt, which is the biggest rice producer in both the Middle East and the African continent, started with a capture-type of rice-fish farming based totally on occasional fish stock coming in with the irrigation water. Limited experiments using carps in the early 1970s were conducted with encouraging results (Essawi and Ishak 1975). The rice-fish farming area expanded considerably using reclaimed salt-affected lands and in 1989 reached a peak of 225 000 ha. As rice prices increased, however, HYVs were adopted and reclaimed lands were used for rice monoculture. This resulted in a drop in the rice-fish area to 172 800 ha by 1995. Nonetheless the 1995 fish production from rice fields accounted for 32% of the total aquaculture production in the country (Shehadeh and Feidi 1996). Since then 58 000 ha of farmland have been added producing 7 000 t of *C.carpio* in 1997 (Wassef 2000).

Iran

Iran begun rice-fish culture trials in 1997 (personal communication, Mr Ibrahim Maygoli, Shilat Aquaculture Division Head, Tehran, Iran, 30 August 1999). With good results obtained, 18 farms with a total area of 12 ha adopted the technology. Chinese major carps are used concurrently with rice, sometimes with supplementary feeding. Productions over 1.5 t of fish per ha together with 7 t of rice have been achieved with a high survival rate (96%), despite an average water temperature of only 23°C during the culture period. In addition, 70 farms have adopted a rotational rice-fish farming system where the rice field is stocked with trout during the winter months when the average water temperature is 12°C, yielding 640 kg · ha^{-1}. Concurrent culture of *M. rosenbergii* with rice is also being tried.

10.6 Europe

Rice is not a major crop in Europe and is relatively important only in Italy (216 000 ha of rice land) producing 59% of the European Union's (EU) rice production. Spain with 86 000 ha comes a distant second, contributing only 25% of the EU production. The other European countries producing rice are Albania, Bulgaria, France, Greece, Hungary, Macedonia, Romania, and Yugoslavia.

Italy

Rice-fish culture was introduced to Italy at the end of the 19th century and was to progressively become important during the subsequent 40 years. The main species were *C. carpio, C. auratus* and *Tinca tinca*. The rice fields were used to produce fingerlings that had a ready market among pond owners and angling society. The practice gradually declined and by 1967 it was no longer considered an important activity. The cause of its decline was traced to economic, social and technical factors. As rice farmers abandoned traditional practices to increase rice production, the production of fish became less and less compatible with these new practices (Coche 1967). There is a renewed interest in investigating fisheries management in rice fields including ecological and economic aspects under modern methods of cultivation at the University of Bologna.

Hungary

In Hungary where irrigated rice land once covered 45 000 ha, *C. carpio* was cultured in the flooded fields by the cooperative and state farms to reduce production costs. In the absence of marine fish, freshwater fish commanded a good price thus boosting the farmers' income. It was also reported that fish helped keep the fields clean. With the total rice hectarage down to only 5 000 ha as of 1992, there is no published information as to whether any of the rice fields are still cultivating fish.

10.7 The Former Soviet Union

Although wheat is the most important grain for most of the former Soviet Union countries, rice is grown in some of the Central Asian republics and many have tried or practiced rice-fish culture.

Fernando's et al. (1979) listing of publications dealing with the aquatic fauna of the world's rice fields had 55 entries from the former Soviet Union, of which 12 dealt specifically with rice-fish culture. This is a large number considering that the bibliography had a total of 931 entries from 61 different countries and territories. By way of comparison the US had a total of 70 papers listed, 89 for India, and 54 for Japan.

The most authoritative historical review for this region is by Meien (1940).

10.8 South America and the Caribbean

Although rice is produced in nine countries in South America and eight countries in the Caribbean, the culture of fish in rice fields is not widespread. As early as the 1940s, experiments were being conducted in Argentina on the culture of kingfish (*Atherina bonariensis)* in rice fields as a food fish and for the control of mosquitoes (Macdonagh 1946 as extracted from FAO 1957). Attempts were also made to introduce the concept in the British West Indies and the British Guiana in the early 1950s (Chacko and Ganapati 1952 as extracted from FAO 1957).

Experiments on integrating fish culture with rice production are, or were, being conducted in Brazil, Haiti, Panama and Peru, but only Brazil appears to have had some degree of commercial success. Extensive rice-fish culture had its beginnings in the valley of Rio São Francisco (northeast) and in the rice fields in the south. In the northeast, farmers became interested in semi-intensive rice-fish culture using native fish species caught in lakes along the river such as curimatá pacu (*Prochilodus argentes*), piau verdadeiro (*Leporimus elongatus*), and mandi arnarelo (*Pimelodus clarias*). Experiments on intensive rice-fish culture were also conducted in the Paraíba basin using the *C. carpio* and Congo tilapia (*T. rendalli*) (Guillen 1990). The outlook for rice-fish culture is thought to be favorable for the region because of its suitable climate and irrigated areas. Recent FAO-facilitated community work focuses on the promotion of aquaculture and other integrated production methods in rice-based systems in Guyana and Suriname.

10.9 The United States

Rice-fish farming used to be considered important in the United States. After the rice had been harvested, the rice lands were flooded and stocked mainly with *C. carpio*, bigmouth buffalo (*Ictiobus cyprinellus*), and channel catfish (*Ictalurus punctatus*). In 1954, some 4 000 ha of woodlands in Arkansas were diked, flooded, and stocked with fish. In 1956 this increased to 30 000 ha and reportedly produced 3 200 t of fish. Demand for fingerlings shot up and new hatcheries had to be put into operation.

The growing importance of rice-fish farming and the need to improve existing practices led the US Congress to enact the Fish Rice Rotation Act of 1958 for the Secretary of the Interior (who then had jurisdiction over the Fish and Wildlife Service) to implement. Its objective was "to establish a program for the purpose of carrying on certain research and experimentation to develop methods for the commercial production of fish on flooded rice acreage in rotation with rice field crops, and for other purposes." To carry out the studies on rice-fish rotation a research station, which was to become the Stuttgart National Aquaculture Research Center (SNARC), was established in Stuttgart, Arkansas.

By 1960, a survey of 53 selected farmers in the states of Arkansas, Louisiana and Mississippi showed that 20.4% of the total water surface area was used for fish culture. At that time there were 1.25 million ha of irrigated rice lands in the US and the potential for fish culture was considered great. Coche (1967) thought the industry had bright prospects, saying, "There is little doubt that a new area of intensive development can be forecast for fish culture in the vast complex of US rice fields."

As technology evolved and because of new economic realities, interest in rice-fish farming appears to have waned sometime after the 1960s. This can be surmised from the shift in the research direction of SNARC.

Nonetheless, the concept of fish-rice rotation on a commercial scale is far from dead in the US. However, instead of finfish, crawfish are now being rotated with rice. Two crawfish species are popular because of their hardiness and adaptability, the red swamp crawfish (*Procambarus clarkii*) and to a certain extent the white river crawfish (*P. zonangulus*). The life-cycle of crawfish and environmental requirements lend very well to being rotated with rice and even with rice and soybeans. Most of the crawfish produced in the US now come from the rice fields of the southern states (De La Bretonne and Remaire 1990).

11. Prospects and Program for the Future

11.1 Prospects

It is now an opportune time to promote rice-fish farming. Integrated rice-fish farming has been practiced for some time but has failed to become so common as to become second nature to rice farmers. Interest in rice-fish farming over the years has waxed and waned among policy-makers, scientists, extension workers and farmers in different countries. This is understandable given the circumstances during particular periods. Now is a good time to rekindle the interest among all sectors since policy-makers, researchers, extension workers and farmers might be more receptive due to the convergence of four factors.

First, capture fisheries has in many areas reached its limit. Increasing aquaculture production is one obvious solution to meet growing demands, and the world's rice fields represent millions of hectares of fish growing areas. The 1996 World Food Summit agreed "to promote the development of environmentally sound and sustainable aquaculture well integrated into rural, agricultural and coastal development."

Second, there is a growing recognition of the need to "work with" rather than "against" nature. Integrated pest management (IPM) is being promoted in the place of extensive use of pesticides, and fish have been found to be an effective pest control agent. Chemical pesticides are a double-edged sword that can be as injurious to human health and the environment as to its targeted pests.

Third, fresh water is a limited resource and the integration of fish with rice is one way of using water more efficiently by producing both aquatic animals and rice. In addition, new land suitable for aquaculture is limited and the culture of fish together with rice is an effective way of utilizing scarce land resources.

Fourth, rice is not a purely economic commodity; in many countries it is a political commodity as well. The farm gate price of rice is not always based on providing a just economic return to the farmers, but often has political implications such as national food security and export potential. The market, however, usually determines the price of fish. While growing fish in a rice field entails minimal incremental costs, it is one way of augmenting the farmers' income.

These developments serve as an impetus for promoting rice-fish farming. Together, these trends cover various concerns of all sectors involved in rice farming.

11.2 Major Issues and Constraints

Several concerns over rice-fish culture have been identified (in a working paper prepared for the 16th Session of the International Rice Commission, 1985).

- The greater water depth required in rice-fish farming than in traditional rice cultivation may be a limiting factor if the water supply is inadequate. As discussed earlier, increased leaks, seepage and percolation due to maintaining deeper standing water in rice-fish culture can increase water needs significantly.
- Fish cause damage to rice plants which they uproot and eat them. Destructiveness of fish on the rice crop has been observed, particularly when bottom-dwelling *C. carpio* are stocked too early after crop establishment and the transplanted rice seedlings have not developed a good root system, or when herbivorous fish such as *C. idellus* are stocked at larger sizes capable of consuming whole plants. These problems can easily be avoided by good management practices including species selection, stocking size and timing of stocking.
- More fertilizers are needed to increase the primary productivity of the water and feed the fish. Increased fertilization is assumed since both the rice and the phytoplankton require nutrients. The increased fertilization was first estimated by Chen (1954) to range from 50 to 100%. However, experience has shown that in most cases the fertilizer requirement decreased with the introduction of fish (Gupta et al. 1998; Israel et al. 1994; Yunus et al. 1992). Cagauan (1995) found that a rice field with fish has a higher capacity to produce and capture nitrogen (N) than one without fish.
- A small percentage of the cultivable area is lost through the construction of drains and shelter holes resulting in reduction of the paddy yield. Again, experience has shown that the

rice yield often increases in rice-fish culture and thus the excavation of a small part of the rice field (normally no more than 10%) often results in no net loss but rather a net gain in rice production.

- The use of short-stemmed, high yielding rice varieties is limited by the deeper standing water required for rice-fish farming. Even IR36, which has a tiller height of 85 cm, has been successfully used for rice-fish farming. Costa-Pierce and De la Cruz (1992) found that widespread use of HYV was not considered a major constraint in rice-fish culture in most countries,[21] neither was pesticide usage. In fact, as was pointed out at the 19th Session of the International Rice Commission, the case of the P.R. China with 1.2 million ha under rice-fish farming in a rice area almost exclusively planted with modern varieties shows that the use of these varieties does not appear to be a constraint for rice-fish farming (Halwart 1999, Table 17).
- The use of pesticides will be limited. It is argued here that reduced use of pesticides is an advantage to farmers, the communities and the environment in general. Studies undertaken in Bangladesh have revealed that rice-fish farmers use less than 50% pesticides than that used by rice-only farmers (Gupta et al. 1998). Saturno (1994) observed that farmers are less likely to use pesticides when fish are stocked in their rice fields and still enjoyed high yields. Kenmore and Halwart (1998) have pointed out that elimination of nearly all pesticides in rice fields of farmers who have undergone IPM training results in a higher biodiversity of frogs, snails, aquatic insects and others which frequently is used by farmers in a sustainable manner.
- The farmer has to make a greater initial investment for installations in the rice field (higher bunds, drains, shelter holes). The initial investment is a factor that retards a widespread adoption of rice-fish culture. It is a disadvantage in increasing a farmer's financial exposure, but the potential returns can be very rewarding and the risks are often low.
- The practice of multiple cropping (several annual rotations) will be limited because the fields are flooded for a shorter period - four months compared with six to eight months, in the case of the annual crop. On the contrary, continuous flooding from six to eight months is advantageous to rice-fish farming since it makes it possible to grow the fish to larger size.

Many constraints that are not inherent to rice-fish farming, but apply to aquaculture and agriculture in general, such as lack of seeds and credit facilities, have been identified (Costa-Pierce and De la Cruz 1992). Some are site-specific, for example the natural flooding cycle (Bangladesh, Cambodia and Vietnam) and poor soils (Indonesia and Thailand). However, it is argued that the major constraint to adoption by more farmers is the fact that rice-fish farming is not part of the mainstream agronomic practice.

11.3 Research and Development Needs

There is a need to refine rice-fish farming, where the thrust is on improving fish production without affecting rice production. De la Cruz et al. (1992) identified possible areas and topics for research for various countries. Topics common to several countries where rice-fish farming is practiced or has high potential are:

- Ecological studies specifically on food webs and nutrient cycle in a rice field ecosystem;
- Determination of the carrying capacity and optimum stocking densities;
- Development of rice field hatchery and/or nursery system;
- Development of rice-fish farming models specific to different agroclimatic zones;
- Optimum fertilization rates and fertilization methods;
- Evaluation of new fish species for rice field culture;
- Evaluation of different fish species in the control of rice pests and diseases;
- Development of fish aggregating and fish harvesting techniques for rice fields; and
- Optimal rice planting patterns for rice-fish farming.

Other topics identified are not necessarily specific to rice-fish farming and may be covered by regular aquaculture research, such as fish nutrition and feed development, or in agronomy, for example weed ecology and management. Long-term, "wish list" research includes the development of new rice varieties for different rice-fish systems.

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[21] With the exception of the Philippines.

Fernando and Halwart (2000) argue that a systematic approach to fish farming development is needed at irrigation system level which will alleviate most of the constraints that are met when trying to promote fish farming in rice fields only. One important task is to classify rice-producing areas for their suitability for rice-fish farming, considering the capacity of the irrigation infrastructure, general soil characteristics, physical requirements as well as the socio-economic situation. The result could serve as a guide as to where to concentrate greater effort in promoting rice-fish culture. The availability of materials from China may be useful to field-test some systems for possible adoption in other countries.

It will be useful if socioeconomic studies are conducted before and after the introduction/ promotion of rice-fish culture. Baseline data on income status and diet will be important in assessing the full impact of rice-fish technology. Deepwater rice systems warrant more studies as such areas could be natural places for fish culture. Low yields of such systems could potentially be compensated by fish yields as Dehadrai (1992) reported yields of 1 100 $kg \cdot ha^{-1} \cdot crop^{-1}$ in India and 650 $kg \cdot ha^{-1}$ in four months in Bangladesh (Ali et al. 1993), although the system was not found financially viable due to the cost of the 4 m high net enclosure.

The rising sea level may necessitate research into brackishwater rice-fish farming. Penaeid shrimps grown concurrently with rice in brackish water as demonstrated in Vietnam (Mai et al. 1992), and in India, the *pokhali* and *Khazan* systems,with salt-resistant rice are reported to produce 885-2 135 $kg \cdot ha^{-1} \cdot crop^{-1}$ of giant tiger shrimps and mullets and 500-2 000 $kg \cdot ha^{-1} \cdot crop^{-1}$ of shrimps and perches, respectively. The *sawah-tambak* (Indonesia) may be appropriate for low-lying coastal areas suffering from saltwater intrusion as it produces 2 000-3 500 $kg \cdot ha^{-1} \cdot year^{-1}$ of brackishwater species (such as penaeid shrimps, milkfish and seabass). It may also be possible to use abandoned shrimp farms for rice-shrimp farming, as many such farms were originally rice fields.

11.4 Institutional Policy and Support Services

11.4.1 Mainstreaming rice-fish farming

People involved in rice production often regard rice-fish farming as a novelty, and standard literature on plant protection in rice production (e.g. Heinrichs 1994; Reissig et al. 1986) does not mention fish as a possible bio-control agent or rice-fish culture. To address this, rice-fish farming should be made part of the agriculture curriculum in universities and colleges, and recognized as a viable farming system.

If possible the agriculture ministry, or its equivalent, in rice producing countries should make integrated rice-fish farming part of the standard agronomic practice so it becomes a logical and viable option for farmers.

Since IPM is now an accepted approach to pest control this is a logical entry point for raising fish in rice fields. However, suitable curricula for the Farmer Field Schools still need to be developed.

11.4.2 Popularization of the concept

Many farmers are aware that fish can be cultured with rice, but few realize the advantages. A major concern is likely to be how to deal with insect infestations when growing fish in the fields. Since governments are often promoting IPM for rice cultivation, the culture of fish should be considered as part of IPM methods as fish cultivation can be effective in strengthening other non-chemical IPM strategies (Kamp and Gregory 1994) and better utilization of resources. Increased income and a healthy crop of rice reinforce farmers' acceptance of non-chemical IPM and rejection of pesticides (Kenmore and Halwart 1998).

Rice-fish farming should become part of public awareness so the culture of fish in rice fields becomes as integral to rice growing as fertilizer application. In fact not too long ago, before the promotion of chemical pesticides, fish and other aquatic organisms were the most natural thing to have in the flood water of rice fields. This continues to be the case for example in parts of Cambodia, the Lao PDR and other parts of Southeast Asia where pesticide use is negligible.

11.4.3 Training and education

Generating public awareness alone is not sufficient however. It may lead to frustration if suitable technologies cannot be delivered. Farmers should know where to turn for assistance. To do this it is necessary to train and re-orient agricultural extension officers. Agriculturists rather than fisheries officers should be targeted for such training since they are the persons who are most often in contact with the rice farmers.

Beyond short-term training for agricultural extension officers, agricultural school curricula should include rice-fish culture as a viable farming system, and the role of fish in pest management should also be taught. Textbooks on rice farming should include sections on rice-fish farming. All those involved in rice production should be made aware that the advantages of rice-fish farming go beyond the production of fish.

11.4.4 Fingerling supply

A vital input in rice-fish farming is fish seed for stocking. In countries where aquaculture is not an important industry, fingerlings are scarce and expensive. There are many issues pertaining to how to successfully promote fingerling production, but this is common for all aquaculture and not specific to rice-fish culture. Any effort to promote a wider adoption of rice-fish farming needs to be accompanied by developing local capability in fingerling production. This could be done through the rice farmers themselves as has been successfully done in Madagascar where a network of private fingerling producers was set up gradually. As a private producer became operational, fingerling distribution by the government in that area was discontinued. In the next step, extension services for rice-fish farmers in the area were included in the marketing strategy for fish seed producers, ranging from demonstrating their own rice-fish operations to organizing meetings. To achieve this, fingerling producers were trained in marketing methods, teaching skills, and extension methods. Activities were supported by a small but highly qualified group of government extension agents (Van den Berg 1996).

11.4.5 Financing

Financing may be required since the raising of dikes and excavation of ponds or trench refuges may incur extra expenses beyond what is normally required for rice farming. Often the amounts involved (US$ 500 or less) are small enough to fall within the scope of micro-credit. Even if hundreds of farmers are to be financed in each locality the total amount involved will certainly be within the capability of rural banking facilities to service. The more critical issue is often to get the financing body to accept this farming practice as a viable venture, as aquaculture has had difficulties in being seen as a low risk farming option.

12. Conclusion

Rice-fish farming offers tremendous potential for food security and poverty alleviation in rural areas. It is an efficient way of using the same land resource to produce both carbohydrate and animal protein concurrently or serially. Water is similarly used to simultaneously produce the two basic foodstuffs.

Fish in the rice field has been shown to be capable of eradicating weeds by eating or uprooting them. It also devours some insect pests not the least of which are stemborers. Experience has shown that the need for chemical pesticides is greatly reduced and in many instances even eliminated. Fish also add to the rice field's fertility and can reduce fertilizer requirements. Integrating aquaculture with agriculture results in an efficient nutrient use through product recycling since many of the agricultural by-products can serve as fertilizer and feed inputs to aquaculture (Willmann et al. 1998). This in turn leads to more fish for the household and can put more cash in the pocket. An important side effect is a cleaner and healthier rural environment.

Other economic impacts can be expected. Rice field modifications may need extra labor beyond what is available within the family, leading to rural employment. Increased fingerling demand may spur the growth of the hatchery and fingerling production business and all other ancillary activities, such as making of hapa nets, harvesting seines, fabrication of hand tools, installation and repair of pumps, among others. Fish need to be marketed and perhaps even processed before marketing. Thus there is a potential to generate additional employment.

The reality is, however, that the adoption rate of rice-fish farming is very low. China with 1.2 million ha used for rice-fish farming is clearly the world leader, but this figure represents only 3.92% of its irrigated area. Surprisingly, it is outside Asia where the rice-fish farms are extensive relative to the irrigated rice fields. In Egypt, the rice-fish farm area represents 37.4% of the irrigated area and in Madagascar, 11.75%. Within Southeast Asia, Thailand is reported to have 2.966 million ha devoted to rice-fish farming and another 25 500 ha related to stocking and managing the fisheries. In all the rest of Asia, the adoption rate is only a little over 1% or there are no statistics available on the extent of rice-fish farming. Should the adoption rate increase to an average 10% of the irrigated rice fields (68.07 million ha), even an annual yield of only 150 $kg \cdot ha^{-1}$ would mean more than 1 million t of fish annually. This figure does not include rainfed areas that also have a potential for fish production.

In order to realize this potential, there is a need for a fundamental shift in attitude towards rice-fish farming in all sectors involved in rice production, from policy-makers to extension officers and farmers. At present rice-fish farming at best is considered a novelty and at worst a fringe activity that does not merit serious consideration in the formulation of national rice production strategies, and is often relegated to a limited set of projects. Further, fishery technologists and scientists are not the appropriate people to best reach out to rice farmers, or to whom rice farmers would listen. The message must be carried by the rice people.

To integrate fisheries and agriculture, Willman et al. (1998) recommend multi-sectoral integration between various government agencies involved in river basin and coastal development and various government agencies that may be involved in fisheries and agriculture. However, the authors also acknowledged the difficulty involved in such integration. While ideal, the case of promoting a more widespread adoption need not involve too many agencies; in fact it should involve only those involved in agriculture.

The various sub-sectors in agriculture need to recognize rice-fish farming as a distinct and viable farming system that farmers can choose to adopt wherever the physical conditions are appropriate. If rice-fish farming is seen as a viable agronomic practice, many of the expenses that go into raising fish in rice fields will be part of legitimate expenses where supervised credit is involved. Fisheries agencies have an important role to play, in seeing that good quality fingerlings are available at the time required by farmers.

Proper guidelines should also be in place to safeguard that the fish culture component not be overdone to the detriment of rice production. With good fish production and high prices farmers tended to enlarge the refuge areas in Viet

Nam (Halwart 1998). Purba (1998) concluded in Indonesia that an increase in fish demand and price would decrease rice production, as the ratio of the refuge to the rice planting area becomes excessive. It should be clear that the objective of raising fish with rice is to increase fish production without lowering rice yields.

With such a shift at the top level, agricultural extension agents can be properly trained to promote and demonstrate the "new" technology. In this manner, the popularization of rice-fish integration will not be limited to a few farmers under a special project, although it may be initiated in such a manner. Widespread introduction of rice-fish concepts to communities, coupled with demonstrations in farmers' own fields, and linking of the rice-fish approach with the IPM Farmer Field Schools (Kenmore and Halwart 1998) is likely to result in sustained adoption. The farmers themselves are the most effective agents of change. For improved contact with adopters, person-to-person channels are the best mechanisms to obtain information about new technologies. These channels include direct contact with other farmers, extension workers and technical specialists. In India, about 85% of the farmers mentioned other farmers as their sources of information (Librero 1992).

In summary, in order to popularize rice-fish culture, the concept should become part of the agricultural system rather than the fisheries system. The fisheries agencies will need to put further efforts in the establishment of viable national fish seed production and distribution system operated by the private sector so that fingerlings of the desired species are readily available to the farmers. Only then can more fish be found in the rice fields.

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