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Integrated Agriculture-Aquaculture Farming Systems

Edited by
Roger S. V. Pullin and Ziad H. Shehadeh

INTERNATIONAL CENTER FOR LIVING AQUATIC RESOURCES MANAGEMENT

SOUTHEAST ASIAN REGIONAL CENTER FOR GRADUATE
STUDY AND RESEARCH IN AGRICULTURE

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Proceedings of the ICLARM-SEARCA Conference on
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Preface

Integrated livestock-fish, fowl-fish and rice-fish farming and crop rotation in fishponds have been practiced for centuries in Asia.

The integration of aquaculture with livestock and crop farming offers greater efficiency in resource utilization, reduces risk by diversifying crops and provides additional food and income.

However, reliable quantitative production and management guidelines are yet to be generated, recorded and disseminated to serve as a baseline for development programs.

Recognizing this deficiency, the International Center for Living Aquatic Resources Management (ICLARM) began an integrated animal-fish farming research project in 1978, in cooperation with the Freshwater Aquaculture Center of Central Luzon State University, Nueva Ecija, Philippines.

This conference, held in Manila, Philippines, 6 to 9 August 1979, was called in association with that project, to increase awareness of the effectiveness of integrated agriculture-aquaculture farming systems in increasing production and income from small-scale enterprises; encourage governments and assistance agencies to initiate research and development programs to document and test these systems, and stimulate continuing cooperation in this field.

The immediate objectives of the conference were: to provide an overview of integrated agriculture-aquaculture farming systems as currently practiced in a number of Southeast Asian countries; to review available experience and technology; to discuss the social and economic aspects of these systems and identify research and development requirements. It was financially supported by the Rockefeller Foundation and co-sponsored by ICLARM and the Southeast Asian Regional Center for Graduate Study and Research in Agriculture (SEARCA).

Two symposia on integrated farming and the use of livestock wastes have been organized since the present conference: The Philippine Council for Agriculture and Resources Research (PCARR) symposium/workshop, entitled *Agribusiness Systems for Integrated Crop-Livestock-Fish Farming*, held in Los Baños, Laguna, Philippines, 19 to 25 November 1979, and an International Symposium on Biogas, Microalgae and Livestock Wastes in Taipei, Taiwan, 15 to 17 September 1980, organized by the Council for Agricultural Planning and Development.

As a follow-up to the conference, ICLARM has produced a bibliography on rice-fish culture, with a view to establishing a document retrieval service on this subject. Further bibliographies are planned on other aspects of integrated farming. ICLARM will also continue to seek financial support to expand its research initiative with Central Luzon State University into a regional research network.

We would like to thank our co-sponsors and participants at the conference for their valuable contributions towards progress in integrated agriculture-aquaculture farming methodology.

R. S. V. PULLIN
Z. H. SHEHADEH
September 1980

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REVIEWS AND BACKGROUND PAPERS: AQUACULTURE IN RICE FIELDS AND IRRIGATION SYSTEMS

Review of Rice-Fish Culture in Southeast Asia

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Abstract

The methods of fish culture in Southeast Asian rice fields are reviewed with comparisons between the captural system (in which stocking is by simple introduction in irrigation water and inputs and preparation are minimal) and the cultural systems (in which fields are prepared for fish and deliberate stocking is practiced). There are two main types of cultural system, concurrent and rotational culture of rice and fish. The numerous fish species cultured in rice fields and their effects on the rice are evaluated. The constraints to rice-fish culture, particularly pesticide use, are discussed and assessment is made of the prospects for future development.

Introduction

Rice is the dominant cereal crop in Asia. It is the staple food of over 1.4 billion people in the world, mostly in Asia where 90% of all rice is grown and eaten. Rice is the main dietary source of carbohydrates for the people of Southeast Asia; it contributes half or more than half of their available calorie supply. For most rural farmers, this single crop is virtually their sole livelihood. It occupies between half and two-thirds of the total arable land available in the principal rice-producing countries. It also contributes up to 20% of their entire gross domestic product.

Rice itself is not a complete food; a rice diet must be supplemented with animal proteins. In Southeast Asia, the most important and cheapest source of animal protein, traditionally, is fish. The annual fish consumption per capita is from 20 to 25 kg in Malaysia and Thailand. In the Philippines and Vietnam, it is a little under 30 kg.

The practice of collecting wild, naturally occurring fish for food from rice fields is probably as old as rice cultivation itself. It has been suggested by Tamura (1961) that fish culture in rice fields was introduced into Southeast Asia from India about 1,500 yr ago. Rice-fish culture in Indonesia started somewhere in the middle of the 19th century (Ardiwinata 1957). Its early development in Indonesia was associated with religious schools and later government agencies.

The oldest written record of rice-fish culture in Japan dates from 1844 although it is believed that it has been practiced long before that (Tamura 1961). The problems of food supplies during the Second World War gave an impetus for extensive fish culture in rice fields. In 1909 only 401.8 t of fish was produced from rice-fish culture whereas in 1943 a yield of 4,437.7 t was harvested (Nambiar 1970). As soon as sea fish became available, farmers lost interest in raising fish and the production fell to less than one ton (Hickling 1962). Another reason for the decline in rice-fish culture has been the introduction of various insecticides which are harmful to fish.

While the total area of irrigated rice fields in Southeast Asia is estimated to be about 21 million ha, only 0.65% or 136,000 ha are used for culturing fish (Coche 1967). The potential for development is still very great and rice-fish culture is one of the best and most rational means of using agricultural land.

Rice-fish culture plays an important role in the rural economy of Southeast Asia. This is because fish culture lends itself well to small labor-intensive farming operations; it can be used in conjunction with rice cultivation to increase productivity. In the central region of Thailand, Pongsuwana (1963) observed that the income derived from fish culture was equal to or even higher than that from rice production itself. In Java, experienced tenant farmers cede the entire rice crop to landowners in exchange for the right to culture fish in the rice fields. Thus fish production plays a very important role in the economy of rice farmers, especially those who do not own land. In Malaysia, it was estimated that over 60% of rice farmers were tenant farmers. Similarly in Indonesia, only 42% of farmers own land themselves and the rest are tenant farmers (Ardiwinata 1957). Of the farms in Java, 42% are smaller than 0.5 ha, 45% between 0.5 and 2.67 ha, and 12% larger than 2.67 ha. The rent for land is very high, landowners collect about 50%-100% of the yield of rice. Under such severe leasing terms, farmers depend heavily on fish culture.

Methods of Fish Culture in Rice Fields

The techniques used for rice-fish culture differ considerably from country to country. Even within one country, for example Indonesia, the techniques in each region may be different (Ardiwinata 1957). In general the different types of exploitation of rice field fisheries may be classified as follows:

1. Captural system. In this system there is no stocking of the rice fields with fish. Wild fish populate and reproduce in the flooded rice fields and are harvested at the end of the rice growing season. Captural systems occupy a far greater area than cultural systems and are important in all the rice growing areas of Southeast Asia.
2. Cultural system. In this system the rice field is deliberately stocked with fish as in a fish pond. Even within this system it is necessary to differentiate between simultaneous and alternate production when referring to the harvest of rice and fish. Hence the cultural system may be further differentiated into:
   a. Concurrent culture—where the fish is reared concurrently with the growing of the rice crop.
   b. Rotation—where the fish is cultured as a single annual crop of rice, as in the "Palawidja method" practiced in Indonesia. Fish can also be cultured as an intermediate crop between the rice harvest and the next replanting, as in the "Panjelang method" in Indonesia.

THE CAPTURAL SYSTEM

In the captural system there is very little input towards the culture of fish. The fields are not especially prepared for the retention of fish, except for the digging of sumps, about 40 to 50 m^2 in area and 2 m deep, in the lowest region of a group of fields.

The current practice in Peninsular Malaysia is to harvest the wild fish stocks which make their way into rice fields when flooded. This captural system has been very successful due to the introduction of *Trichogaster pectoralis* from Thailand into the rice-growing areas (Soong 1951); it has established itself as the main fish crop. In addition to *T. pectoralis,* three other species, *Clarias macrocephalus, Ophicephalus striatus* and *Anabas testudineus,* are also caught.

THE CULTURAL SYSTEM—CONCURRENT CULTURE

The concurrent production of rice and fish has a number of advantages. The presence of fish increases rice production and also helps to control weeds, molluscs and harmful insects. There must, however, be adequate water, both in flow as well as depth. Not all varieties of rice can tolerate deeper water and the required dikes, draining ditches, and capturing sumps take up between 5 and 10% of the field. This loss in space is compensated for by increased rice yields, as well as by added income from the fish.

In addition to the requirement for a higher water level, concurrent rice-fish culture limits the use of modern agricultural techniques, especially chemical fertilizers, insecticides and herbicides. In a number of areas it is slowly being discarded in favor of the rotation methods.

The actual production varies from country to country. In Indonesia, the following method is used. Initially the rice field is prepared by digging peripheral trenches 50 cm wide and 30 cm deep, building bunds 25 cm high and placing bamboo pipes and screens at the inlet and the outlet (Figure 1).

The first stocking of common carp (*Cyprinus carpio*) takes place five days after the rice has been transplanted, at a rate of about 60,000 1-cm fry/ha. During the first weeding, 3 wk after replanting, the field is drained and the fish takes refuge in the trenches. At the second weeding, 5 wk after replanting, the fry (3 to 5 cm) are harvested and sold.

After the second weeding, the rice field is used to raise a second crop of fish for food. The second stocking is made with 8 to 10-cm fingerlings at the rate of 1,000 to 2,000/ha. One and a half months later, the rice fields are slowly drained and fish of 14 to 16 cm weighing between 50 to 70 g are harvested. The yield varies between 75 and 100 kg/ha.

In Western Java, *Sarotherodon mossambicus* is cultured simultaneously with rice. The fields are pre-

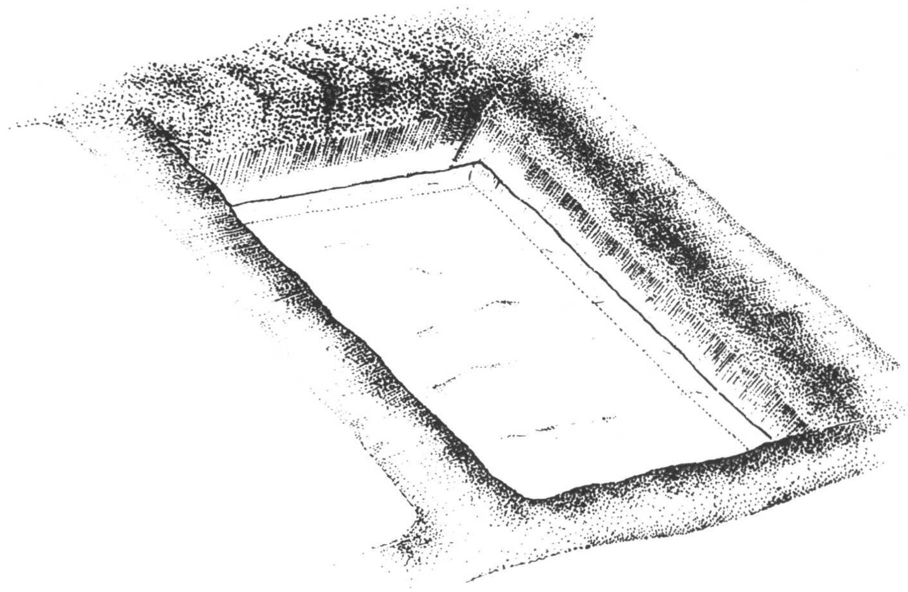

Figure 1. Field preparation for rice-fish culture in Indonesia showing the peripheral trench.

pared as for common carp. A week after the transplanting of rice, the first stocking is made with 1,000 to 10,000 1 to 3-cm fry, together with a few hundred adults/ha. Six weeks later, the largest fish are harvested for consumption and the remainder returned for another six weeks.

In contrast to this very short fish production cycle, the Japanese farmers culture their common carp for 2 to 3 yr. In Japan the fields are prepared by constructing bunds of 40 to 45 cm high around each field. These bunds are about 30 cm wide and are reinforced by various means, such as embedding straw along the inside walls. A sump of a few square meters and about 60 cm depth is dug near the water inlet. A few channels of 30 cm width extend from the sump to the opposite end of the field (Figure 2). Water is supplied to the upper part of the field through a simple inlet. The outlet is placed diagonally opposite. Both the inlet and outlet are encircled by bamboo screens to prevent the passage of fish. The water depth is kept between 6 to 18 cm during the growing season.

The fields are normally stocked with common carp about 7 to 10 d after transplantation of the rice. The stocking rate depends on the size of the fish and the environmental conditions. The usual practice is to stock 3,000 to 6,000 fry/ha. Supplemental food which usually includes silkworm pupae is given to the fish on a daily basis.

The fish are harvested about a week before the harvest of rice. If yearlings are harvested, they are stocked in over-wintering ponds until the next spring, when they are restocked for a second year to produce fish of marketable size. Some fish are reared for a third year until they reach a weight of more than 350 g.

THE CULTURAL SYSTEM–ROTATION OF RICE AND FISH

Rotation permits better care for both rice and fish. It allows the use of machinery, insecticides and herbicides for rice production. It also allows greater water depth for fish production.

Under the Palawidja method of Indonesia, a single annual crop of fish is cultured after the single rice crop. While rice is being cultivated, the farmer can direct all his energy towards the improvement of the rice plants. One or two weeks after rice has been harvested, the field is prepared for the culture of fish. Bunds of 50 cm height are built around each field and ditches of 50 cm width and 30 cm depth are constructed around the field. Simple bamboo pipes and screens are placed at the inlet and outlet to prevent the passage of fish and debris.

Common carp is the main fish grown; other species are of minor importance. The aim of this type of fish culture is two-fold: to raise fry of 3 to 5 or 5 to 8 cm long, and to grow food fish. The fields are stocked with 1-cm fry at 60,000 to 100,000/ha and grown for 3 wk to produce 3 to 5-cm fry. Alternatively, to produce 5 to 8-cm fry, 2 to 3-cm fry are stocked at 20,000/ha and grown for 3 to 4 wk. When the aim is to produce food, as is often the case towards the fish culture season, 5 to 8-cm fry from the previous period are stocked at 6,000/ha. The period of culture is about 40 d, producing fish of about 100 g.

While the fish are being cultured in the fields, the dikes, inlet and outlet are inspected daily. During heavy rains the inlet is closed. About 2 wk after the stocking of fry, paddy shoots and other vegetation are removed. This is repeated if there is a second fish crop. Predatory birds are scared away during the day.

Another method, which in many ways is similar to that above, is the Panjelang method. This method is also practiced in Indonesia; it involves the cultivation of fish between two rice crops. The method originally aimed to produce food fish for the farmers but, as freshwater fish culture expanded, the fields became used mainly for the production of fry for which there is a ready market. The fields are prepared as in the Palawidja method and the stocking rates and fry sizes are also similar in most areas. In the East Garut region of Java, fry are stocked at a density of 20,000 to 30,000/ha to provide 3 to 5-cm fry after 30 d culture. The average yield is about 15,000 5-cm to 8-cm fry, i.e., about 54 kg/ha. Part of the fry produced after the first month are restocked at 4,000 to 5,000/ha and grown to food fish size.

Physical Modifications of Rice Fields and Water Demands

Certain physical modifications must be made to rice fields for fish culture. First, the height of the bunds surrounding the field must be raised to give an adequate depth of water. This must be at least 10 cm for part of the culture period and an inflow is required at intervals to meet the increasing requirements for space, oxygen and nutrients of the growing fish. The depth of water required depends on the size and type of fish cultured. Javanese farmers maintain depths from 4 to 20 cm, depending on the size of fish being cultured, while in India depths from 10 to 60 cm are maintained. For the culture of tilapias, a depth of 7.5 cm of water is sufficient (Hora & Pillay 1962). In China, the water level in rice fields reaches a maximum of 15 cm (China Freshwater Fish Committee 1973).

For the retention of water in rice fields, strong, watertight bunds are also essential. Various simple methods are employed to achieve this. Old existing bunds can either be ploughed and levelled to make way for the construction of new bunds, or they can be repaired. The construction of a new bund is quite

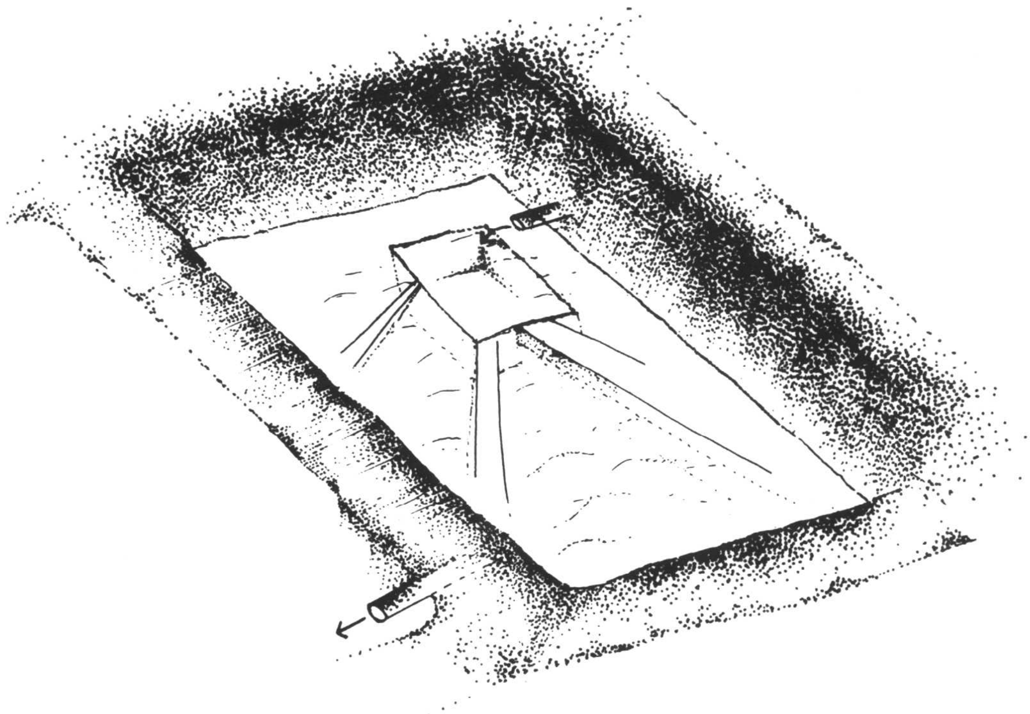

Figure 2. Field preparation for rice-fish culture in Japan showing the inlet, outlet, sump and connecting channels.

simple. Once the old bund has been levelled, a shallow trench measuring 50 cm in width is dug in the ground where the new bund is to be built and filled with new, moist earth that is neither too hard nor too soft and free from grass and weeds. More earth is heaped over this foundation and rammed until the bund is well consolidated and reaches a height of about 35 cm above the field. When this dries, the bund will settle at a height of about 25 cm (Hora & Pillay 1962).

To repair old bunds and to make them impervious, farmers of the Indo-Pacific region, as well as Chinese farmers, just hammer in the sides of the bunds after first removing some earth from the inner side. Such bunds are watertight, and also prevent predators like rats from boring holes (Hora & Pillay 1962). Strengthening of the bunds also prevents soil erosion. In Japan the inner walls of bunds are reinforced by using straw (Kuronuma 1955).

To provide a retreat for fish during periods of temperature extremes or when insecticides and fertilizers are being applied, fish drains or channels are dug, usually on the inner sides of the bunds. The number of channels depends on the size of the field. If a field is large, the channels are peripheral or crosswise. In a narrow rectangular field, however, two or more channels may be dug along the middle of the field. If a field is less than 0.5 ha, a channel around half the perimeter or along two sides of a square field is sufficient. The width of the channel is usually 50 cm and the depth about 30 cm. The best time to excavate the channels is just after rice harvesting (Hora & Pillay 1962). In China channels about 30 cm wide are made by just ploughing the inner bank of the field slightly deeper. Then during transplanting, these channels are deepened so that they are 25 to 30 cm in depth (China Freshwater Fish Committee, 1973).

A sump, approximately 1 m^2 in area, is dug at points where the channels meet (Hora & Pillay 1962). This provides a retreat for fish and aids harvesting. In Japan a sump, called a "kettle," is dug behind the water inlet (Kuronuma 1955). In terraced areas, e.g., Szechuan Province in China, sumps are usually dug on the banks of the fields that do not receive direct sunlight. Occasionally grass and rice straw are placed over the sumps to shield the fish from extreme conditions.

The water inlet and outlet also require some modification before fish can be introduced. They are usually diagonally opposite each other so as to enable the water to cover the whole field evenly. Screening devices at the water inlets and outlets are necessary to prevent the loss of fish and the entry of undesirable species (Figures 3 and 4). In order to deal with floodwater during heavy rains, a spillway should be installed at a suitable height in the field. This should also be screened. Some Chinese farmers use barbed wire, wire netting, bamboo or branches with thorns as screening devices over the mouth of the inlet or outlet pipe, and valves to regulate water flow (China Freshwater Fish Committee, 1973). Japanese farmers use pieces of stones cemented with clay to cover the outlet that is dug through the bund and a wooden gutter to regulate the inflow (Kuronuma 1955).

Species of Fish Used in Rice-Fish Culture

Table 1 gives the species of fish used for concurrent or rotational rice-fish culture. Some of these are also cultured in ponds and storage reservoirs. Suitability for rice field culture requires tolerance of shallow water (average depth about 15 cm), high and variable temperatures (up to 34°C with a 10°C range), high turbidities and low oxygen. Fish differ in their toleration to high temperature. The swamp fish species, *Ophicephalus striatus, Clarias batrachus* and *Trichogaster* spp., are able to withstand higher temperatures than riverine fish. Asian varieties of common carp can tolerate up to 34°C provided that the oxygen content of the water is sufficient. The optimum temperature for common carp culture, however, is around 22°C to 28°C.

Light penetration is reduced by high turbidity of water and, hence, photosynthesis is slowed down. In general, tropical species can tolerate wide ranges of turbidity but prolonged exposure to turbid conditions and extremes of turbidities, as in the paddy fields, favors the growth of olfactory feeders, such as *Clarias* spp., over visual feeders.

Oxygen availability is, however, the major factor limiting fish growth and survival (Soong 1951). In tropical inland waters, the dissolved oxygen content is normally about 70% saturation and adequate for fish. Organic pollution, however, may drop this to dangerously low levels. The minimum level of toleration of dissolved oxygen varies with size and species. Certain fish, among them the anabantids and clarids, possess accessory air-breathing organs and can therefore survive well in waters with very low dissolved oxygen.

The predatory/prey relationship of chosen species for culture should be carefully considered. The snake-head, *Ophicephalus striatus,* is a voracious predator and should not be stocked with its prey species. If a system of polyculture is practiced, the choice of fish should be made such that a balanced ecological system is maintained. Most of the species of fish cultured in rice fields are prolific spawners; this aids stocking whether by deliberate introduction or the passive introduction of eggs and fry from water sources. Stocking with selected "fish nests," fish fry and fingerlings is a deliberate

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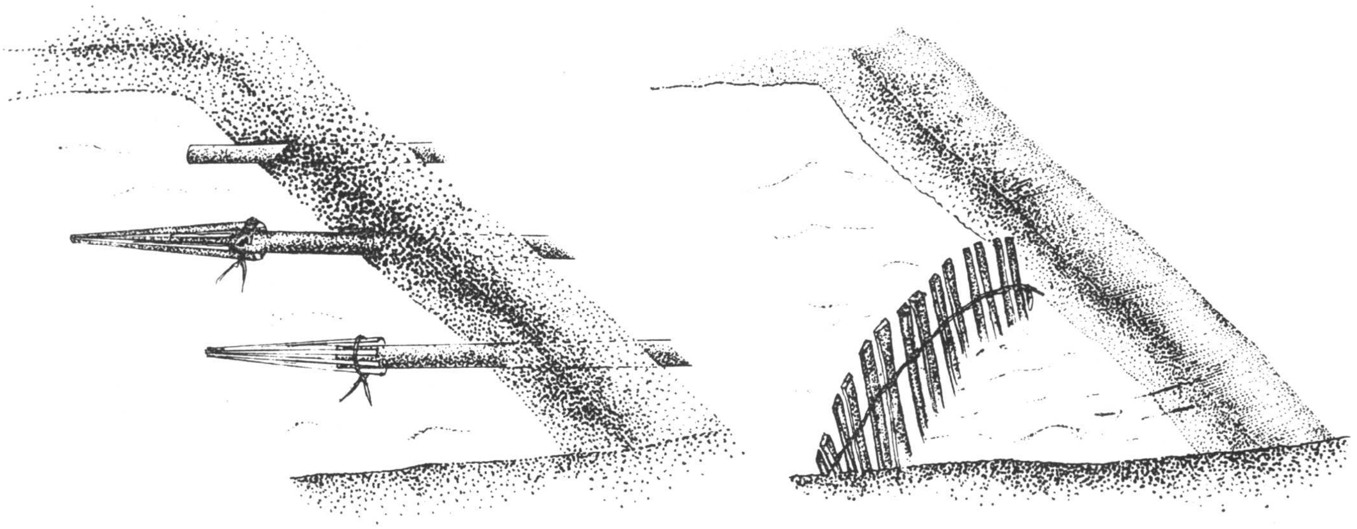

Figures 3 and 4. Screening devices for inlets and outlets from one field used for rice-fish culture.

introduction. These can be obtained from the farmers' own brood stock, government agencies or from other fish farmers. The size of fry or fingerlings that are used varies with species and location. In certain parts of China "fish nests" of the common carp are introduced into rice fields with suitable conditions for hatching (China Freshwater Fish Committee, 1973). In Indonesia the eggs of *Osphronemus gorami* are introduced into the fields and 8 to 11-cm fingerlings harvested and sold for stocking into other farmyard ponds. Male and female *Helostoma temmincki* are also introduced in the rice fields and, when the fry are produced, the young of common carp or *Osteochilus hasseltii* are added (Ardiwinata 1957).

Fry and fingerlings of the various carp species ranging in size from about 1 cm to 12 cm can be introduced into rice fields (China Freshwater Fish Committee 1973). *Puntius gonionotus* fingerlings measuring 5 to 8 cm and *Osphronemus gorami* fingerlings of 8 to 11 cm are also introduced into rice fields in Indonesia (Ardiwinata 1957). Tilapia fingerlings of 9 to 12 cm are stocked in rice fields in China (Tapiador et al. 1977) and in Japan, common carp fry, yearlings and 2-yr-olds have been stocked (Kuronuma 1955). It would be useful to determine the optimum size of the various species relative to their culture periods and markets: fry, fingerlings and food fish. This would minimize wastage of fish, time and money, and optimize the economic returns.

Not much is known about polyculture in rice fields. Where seed fish are introduced passively with the water, various species cohabit the same field. In Malaysia, for example, *Ophicephalus striatus, Trichogaster pectoralis, Trichogaster trichopterus, Clarias batrachus, Anabas testudineus,* and *Puntius gonionotus* are raised. With deliberate stocking, the best combination of species is not well known because this is a relatively recent practice in rice-fish culture. In Indonesia, however, Ardiwinata (1957) reported the following combinations of species: *Helostoma temmincki* (35%), *Osteochilus hasseltii* (15%), *Cyprinus carpio* (15%) and *Puntius gonionotus* (35%); or alternatively, *Sarotherodon mossambicus* (50%), *Helostoma temmincki* (20%), *Osteochilus hasseltii* (15%), *Puntius gonionotus* (15%) and *Cyprinus carpio* (10%).

Table 1. List of fish species harvested from rice fields in Asia.

Anabas testudineus
Carassius auratus
Catla catla
Chanos chanos
Cirrhina mrigala
Clarias batrachus
Cyprinus carpio
Helostoma temmincki
Labeo rohita
Lates calcarifer
Mugil corsula
Mugil parsia
Mugil tade
Ophicephalus striatus
Osteocheilus hasseltii
Puntius gonionotus
Sarotherodon mossambicus
Trichogaster pectoralis
Trichogaster trichopterus

Effects of Fish on Rice

The yield of rice is increased by the introduction of fish into the rice fields. Table 2 gives the cost/ha of rice production for three different areas in Peninsular Malaysia. The costs incurred by a landowner differ from those incurred by a tenant farmer because a landowner has to pay for land and irrigation rates whereas a tenant farmer has to pay rent. It is difficult to estimate with any accuracy the true cost of production of rice in Asian countries since it usually employs family labor.

In Malaysia no additional expenditure is incurred by stocking fish in rice fields as the fish are usually introduced passively with the inflow of water. The physical modifications made to the rice field to accommodate fish may however require some extra input of money if hired labor is employed. Information pertaining to the additional cost incurred for culturing fish in rice fields is rather scanty. The data for Indonesian farmers given by Ardiwinata (1957) lack uniformity and should be further reviewed.

In cases where the rice farmer deliberately stocks fish, e.g., in Indonesia, Japan and China, additional costs for fish production must be considered. These may include payment for fish seed (fry or fingerlings) for supplemental food and additional fertilizers.

The relative importance of fish and rice can be assessed from Tables 3 and 4, which show the importance of fish to landowners and tenant farmers of different segments of land in the Krian District of Perak, Malaysia. These comparisons show that farmers growing a single crop derive a large portion of their income from fish: up to 25% of the rice income for owner farmers and as high as 50% of the rice income for tenant farmers. In view of the relatively high rentals for land, there is little doubt that tenant farmers in single cropping areas depend heavily on the income derived from fish (Tan et al. 1973).

The culture of fish in rice fields generally benefits rice culture. The yield of rice has been increased by about 15% in the Indo-Pacific countries by the introduction of fish (Hora & Pillay 1962). Increases up to 14% have been recorded in China (China Freshwater Fish Committee, 1973) and 7% in Russia (Grist 1965). This probably results from better aeration of the water and greater tillering (Hora & Pillay 1962). The excreta of fish, the additional fertilizers used and any remnants of supplemental food also increase the fertility of soil.

In rice culture, weeds can reduce yield by up to 50% (Coche 1967). The introduction of herbivorous fish controls weeds and reduces weeding labor and costs. Among the most useful species are *Puntius gonionotus, Sarotherodon mossambicus, Trichogaster pectoralis* and *Cyprinus carpio.*

Fish also eat harmful organisms, such as insects and insect larvae. In China, the stem borer is said to have

Table 2. Cost of rice cultivation per hectare per season in Malaysian dollars (US$1.00 = M$2.06) (Based on Selvadurai 1972).

Items	High productivity land: WELLESLEY PROVINCE		Average productivity land: SUNGEI MANIK		Low productivity land: KELANTAN	
	Owner Farmers	Tenant Farmers	Owner Farmers	Tenant Farmers	Owner Farmers	Tenant Farmers
A. Expenses						
Hired labor	191.60	221.39	64.81	62.86	52.19	26.03
Seeds and seedlings	7.76	7.41	7.48	6.35	11.49	12.40
Fertilizers, insecticides	52.24	48.29	20.72	14.55	20.13	15.73
Equipment, buffalo hiring	1.19	4.94	0.59	1.63	1.24	19.59
Land and irrigation rates	11.66	–	8.92	–	8.25	–
Rent on padi land	–	152.05[2]	–	106.16[2]	–	151.86[2]
Subtotal	264.45	434.08	102.52	191.55	93.30	225.61
B. Imputed value of family labor	92.65	94.55	152.23	94.30	170.28	166.45
Subtotal (A & B)	357.10	528.63	254.75	285.85	263.58	392.06
C. Interest on borrowed capital at 6%	207.01[1]	22.01[1]	108.65[1]	15.39[1]	295.91	58.54
Total cost (A, B, & C)	564.11	550.64	363.41	301.24	559.49	450.60

[1] 6% per annum for only one 6 month season in Wellesley and Sungei Manik Provinces where two crops per year are grown.
[2] Rent for one season only.

Table 3. Comparison of yearly incomes per hectare from rice and fish for owner farmers (US$1.00 = M$2.06) (Based on Tan et al. 1973).

	Segment	Net income from rice (M$)	Net income from fish (M$)	% Income from fish
Double cropping segment	A	619.13	32.89	5.31
	B	672.24	64.04	9.53
	C	716.68	48.99	6.84
	D	757.43	47.12	6.22
	E	718.85	30.81	4.29
	F	660.28	37.55	5.69
Average for segments	A-F	704.03	42.86	6.09
Single cropping segment	G	389.83	117.35	30.10
	I	380.29	82.48	21.69
	L	288.07	72.60	25.20
Average for segments	G-L	342.27	90.82	26.53

Table 4. Comparison of yearly incomes per hectare from rice and fish for tenant farmers (US$1.00 = M$2.06) (Based on Tan et al. 1973).

	Segment	Net income from rice (M$)	Net income from fish (M$)	% Income from fish
Double cropping segment	A	278.46	32.89	11.81
	B	331.57	64.05	19.32
	C	376.01	48.99	13.03
	D	416.76	47.12	11.31
	E	378.18	30.81	8.15
	F	319.61	37.55	11.75
Average for segments	A-F	363.36	42.86	11.80
Single cropping segment	G	219.49	117.36	53.47
	I	209.96	82.48	39.28
	L	117.74	72.60	61.66
Average for segments	G-L	171.94	90.82	52.82

been controlled by the introduction of fish (China Freshwater Fish Committee, 1973) and infestation of rats and other pests can also be greatly reduced by the higher and more solid bunds erected for rice-fish culture.

Rice field fish can also contribute to the control of waterborne diseases by feeding on aquatic intermediate hosts, such as mosquito larvae (malaria) and freshwater molluscs (bilharzia).

Rice-fish culture also, however, presents certain disadvantages in addition to the extra water depth and contribution requirements mentioned above. Some fish, such as grass carp, may eat rice seedlings and tilapias may uproot them. Also the presence of fish may complicate the process of draining and drying fields following an outbreak of viral stem rot. In some cases, a decrease in rice yield has been reported with rice-fish culture, e.g., up to about 15% in some areas of Indonesia (Ardiwinata 1957) and unspecified decreases for Taiwan. This is because of the areas taken up by the fish channels which remain unplanted. The income obtained from the sale of fish, however, more than compensates for the loss of rice (Hora & Pillay 1962).

Economics in Relation to Rural Development

The primary purpose of irrigated rice fields is to produce rice. This is the main crop and all cultural operations are directed towards increased rice production. At the same time, it is recognized that rice farmers in Southeast Asia derive relatively low income from rice cultivation alone (Dixon 1971; Selvadurai 1972; Mears et al. 1974). In a survey of rice farmers in the Krian district in Malaysia, Tan et al. (1973) estimated that the average owner farmer earns about M$750* per annum compared to M$400 for the average tenant farmer. With such income they would be among the poorest farm communities if solely dependent on rice culture. It is unlikely, however, that the average farmer depends solely on the income from rice. Many farmers have other sources of income and one of the main traditional sources has always been the sale of fish harvested under the captural system. Hickling (1961) estimated that fish provide an additional income, varying from 20 to 33% of the income from rice culture. The average yield of fish from rice fields using the captural system is about 135 kg/ha (Hora and Pillay 1962). The actual production varies greatly from place to place, depending mainly on water conditions. Soong (1951) estimated that in Malaysia, with neutral pH, the yield was between 220 to 450 kg/ha whereas acidic water gave a much lower yield of 11-56 kg/ha. These yields are much higher than those obtained in Java under the captural system, which are only about 3 kg/ha (Ardiwinata 1957).

Under the cultural system, the yield depends to a large extent on the species stocked, the culture period, the fertility of the soil and water, and the degree of supplemental feeding. Some indications of the yields in some Asian countries are provided in Tables 5 and 6.

Ardiwinata (1967) also reported yields from the various methods of rice-fish culture. Under the Palawidja method (alternate culture of rice and fish) the production of food fish was about 600 kg/ha in fertile waters, 300 kg/ha in moderately fertile waters, and only 100 to 200 kg/ha in infertile waters. For common carp fry culture, production was about 100,000 to 200,000 4 to 5-cm fry, together with about 50 to 100 kg of food fish/ha. Under the Panjelang method (culture of fish between two rice crops), the yield was 40 to 60 kg/ha; 40,000 to 60,000 3 to 5-cm fry or 20,000 to 30,000 5 to 8-cm fry, with in each case an additional 20 to 30 kg of food fish/ha. Farmers culturing *Puntius gonionotus* produced about 80,000 to 100,000 2 to 3-cm fry under the same system. Using *Osteochilus hasselti*, about 75,000 to 90,000 2 to 3-cm fry were produced/ha and using *Helostoma temmincki*, about 1 million. Concurrent rice-common carp culture yielded about 50 to 70 kg/ha of food fish. The corresponding yield for *Puntius gonionotus* was 40 to 60 kg/ha and for both fish stocked together, about 60 to 100 kg/ha.

The value of food fish produced in Indonesia in 1955 was estimated by Ardiwinata (1957) to be 75 million rupiahs for the total production of 9.16 million kilograms of fish. The total number of fry raised was estimated at 3,200 million in 1955. It was not possible to estimate their value as the price of fry varied considerably. Whereas data on actual economics are very vague, it has been estimated that the cost of fry is about 30 to 50% of the value of the fish crop, while maintenance expenses accounted for 5 to 20%, leaving a profit margin of 30 to 65% of the value of the fish cropped.

Constraints to Rice-Fish Culture

While there are many benefits to integrating rice and fish culture, there are also problems. These problems are especially critical for concurrent culture, whether under the captural or cultural systems, as indicated in the reduced rice-fish culture in Japan (Table 7) and Malaysia (Tan et al. 1973).

The recent decline in Malaysia indicates the limitations of the captural system, especially in areas with

*US$1.00 = M$2.06.

Table 5. Fish yields from rice-fish culture using the captural system.

Country	Main fish species	Average annum yield	Source
India (West Bengal and Madras)	Miscellaneous estuarine species (*Lates* spp., *Mugil* spp. and *Mystus* spp.)	100-200 kg/ha/an	Pillay 1958
Indonesia	Miscellaneous species	1.5-3.0 kg/ha/an	Huet 1970
Malaysia	*T. pectoralis*	135 kg/ha/6-10 mo	Hora & Pillay 1962
		(Range 10-400 kg/ha/6-10 mo)	Soong 1955

Table 6. Fish yields from rice-fish culture using the cultural system (Data from Coche, 1967).

Country	Main fish species	Type of culture	Average yield
Indonesia	*C. carpio*	F	150 kg/ha/4-6 mo
	C. carpio	RF	75-100 kg/ha/3-4 mo
Japan	*C. carpio*	RF	100-200 kg/ha/yr
	C. carpio	RF*	700-1,100 kg/ha/yr to 1,100-1,800 kg/ha/yr
Thailand	*C. carpio*	F	80-160 kg/ha/3-6 mo
	C. carpio	RF	10-20 kg/ha/3-4 mo
	C. carpio	RF*	210-250 kg/ha/6 mo
Vietnam	*C. carpio*	F/RF	50-130 kg/ha/10 mo

F - rotational culture of fish and rice
RF - concurrent culture of rice and fish
RF* - concurrent culture of rice and fish with supplemental feeding

Table 7. Rice-fish culture in Japan (From Nambiar 1970).

Year	Area of rice-fish culture (ha)	Production (t)
1909	2,225.7	401.8
1913	2,741.8	599.5
1923	3,856.5	1,206.7
1933	5,691.5	1,923.2
1943	13,896.3	4,437.7
1953	7,743.0	995.7
1963	3,388.0	250.0

double cropping. Here the fields are flooded for a much shorter period of 4 mo, as opposed 6 to 8 mo in single cropped areas. This, together with the extensive use of pesticides, has caused a rapid decrease in fish production. It may be necessary for farmers to change to the cultural system to maintain their income from fish.

Many pesticides used on rice, such as endrin, dieldrin, thiodan (Endosulfan), DDT and Gamma-BHC are toxic to fish (Grist 1965). Their increasing use may produce unacceptable fish mortalities. Figure 5 shows the different insecticides used in Krian, Malaysia. Thiodan is the most frequently used, followed by Malathion and Gamma-BHC (Dol granules, BHC). Sevin is also frequently used, whereas Gusathion, Lebaycid, Dieldrin, Endrin, Agrothion and Dursban are less frequently used (for nomenclature see Table 8).

In Indonesia, it has been estimated that about two million kilograms of insecticides are applied annually to more than one million ha (Hardjamulia and Koesoemadinata 1972). Fish mortalities arising from insecticide usage have resulted in significant financial losses (Saanin 1960).

Some insecticides, such as endrin, dieldrin and thiodan, are very toxic to fish and should not be used in rice fields where fish culture is of economic importance. Increasing awareness of the need for fish conservation has resulted in increased research on pesticide toxicity. The toxicity of some insecticides to *Clarias batrachus* is presented in Table 9. Endrin and thiodan (Endosulfan) are extremely toxic, as is Gamma-BHC, with a 96 hour LC_{50} of 0.13 ppm. Careless washing of thiodan containers has been reported to kill fish in irrigation canals (Tan et al. 1973). Hardjamulia and Koesoemadinata (1972) observed 100% mortality within a few hours of thiodan application (usually within 1 hr) and within 3 hr using Endrin. It is known that thiodan breaks down rapidly in biological systems (Schoettger 1966). Garbach et al. (1971) reported that thiodan at normal application rates breaks down to nontoxic levels within 3 to 5 d in rice fields. In contrast Moulton (1973) maintains that toxicity to fish lasted up to 40 d after application of thiodan granules and up to 26 d after application of thiodan E-C-35 foliar.

Insecticides are not only toxic to fish but may also have detrimental effects on the natural enemies of rice pests. Intensive application of some insecticides may bring about an increase in a normally unimportant but potentially damaging species. For instance, Lim and Hoong (1978) reported that the extensive usage of BHC against stemborers (*Conocephalus* spp.) gave rise to an epidemic buildup of *Sesamia inferens* which occupied the same niche and against which BHC had poor control. The recent increase in the green leafhopper *Nephotettix cincticeps* has also been attributed to a reduction of beneficial predator species through indiscriminate insecticide usage (Kawahara et al. 1971; Sasaba and Kiritani 1972). Hence, insecticides do not always reduce

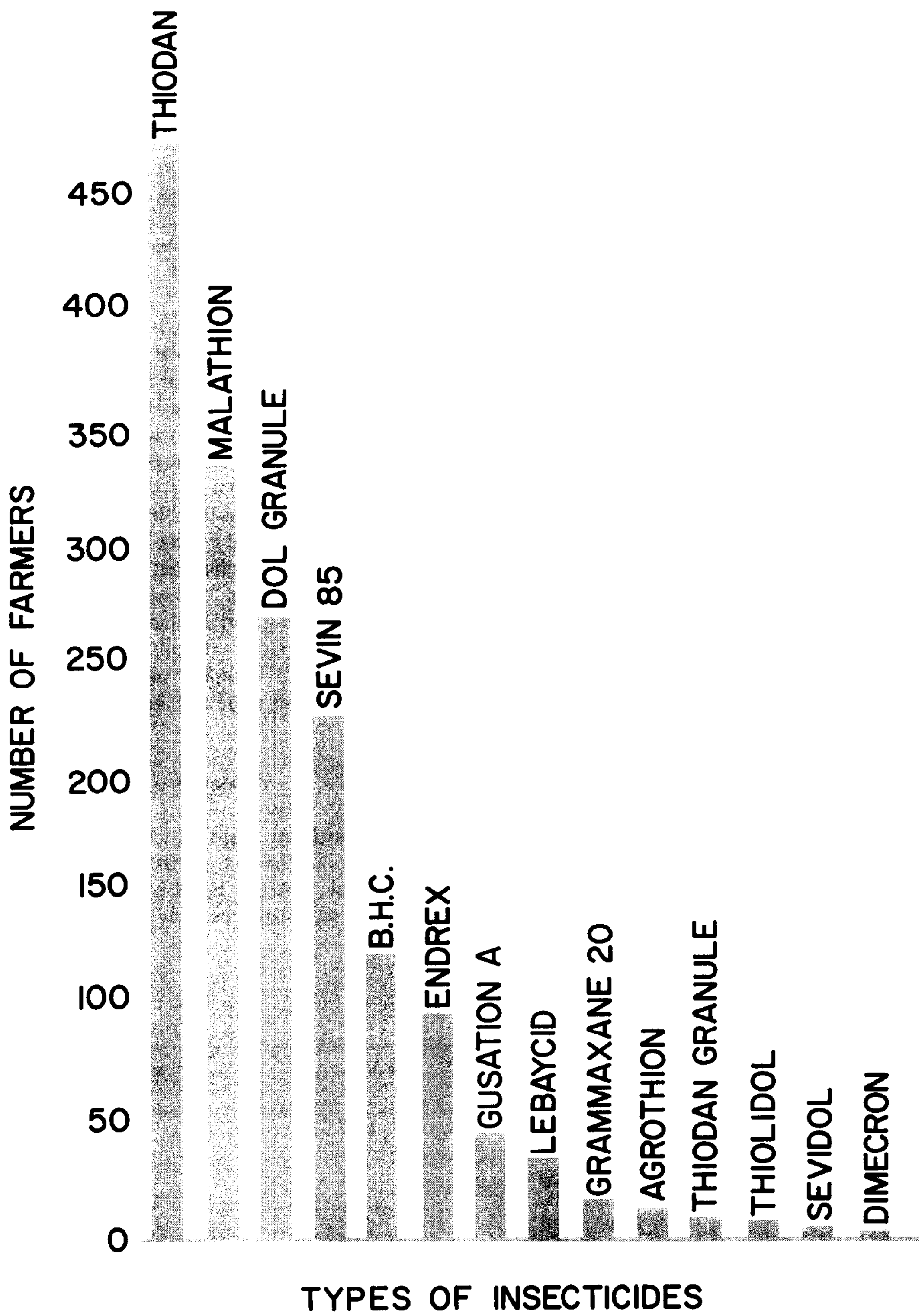

Figure 5. Numbers of farmers using different types of insecticides in Krian, Malaysia, 1973 (see Table 7 for details of nomenclature).

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