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
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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 m²).

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 m² 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" 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, 5 The words "trench" and "ditch" are synonymous here since the two words are used interchangeably in the literature on rice-field fish culture.
The FAO and The WorldFish Center 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
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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 m², 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-Pierce (1992), farmers in Indonesia use a similar approach.

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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 m² 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).

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).
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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.

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.