

# 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.

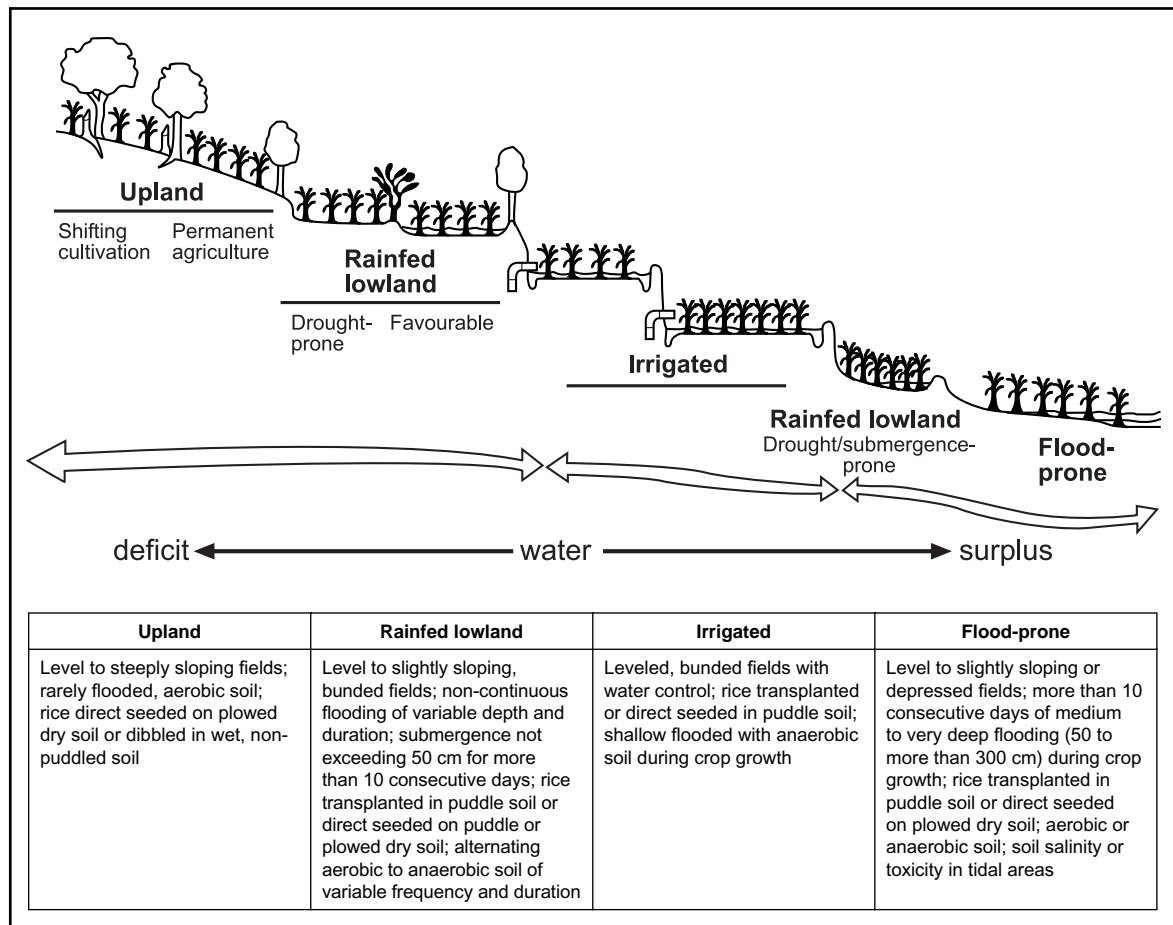


Figure 1. Rice land ecosystems (after Greenland 1997 as adapted from IRRI 1993).

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 ( $\text{NH}_3$ ). 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

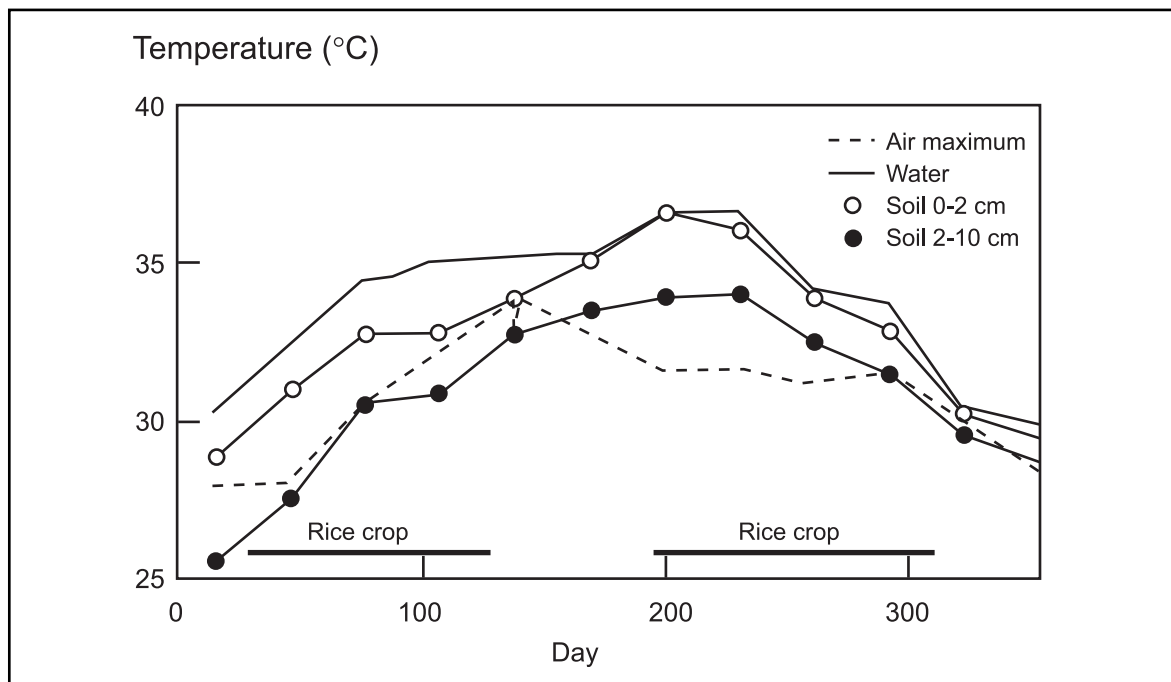


Figure 2. Average monthly values of maximum air temperature and of temperature in the flood water, upper (0-2 cm) and lower (2-10 cm) soil at 1400 hr, IRRI farm, 1987 (Roger 1996).

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 ( $\text{CO}_2$ ) that when dissolved in water forms carbonic acid ( $\text{H}_2\text{CO}_3$ ), which in turn dissociates into bicarbonates ( $\text{HCO}_3^-$ ) and carbonates ( $\text{CO}_3^{2-}$ ). This results in the release of hydrogen ions ( $\text{H}^+$ ) which increase the acidity of the water, and cause the pH to drop. Atmospheric  $\text{CO}_2$  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  $\text{CO}_2$  from the water due to photosynthetic activity causes the hydroxyl ions ( $\text{OH}^-$ ) 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  $\text{CO}_2$  (and thus  $\text{H}^+$  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 ( $\text{pH} > 9.5$ ) waters during times of algal blooms (Roger 1996).

Ammonia ( $\text{NH}_3$ ) is an important source of nitrogen in the rice field. In its ionized form,  $\text{NH}_4^+$ , ammonia is rather harmless to fish, while its unionized form,  $\text{NH}_3$ , is highly toxic. The proportion of the different forms is dependent on the pH of the water, where the  $\text{NH}_3$  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).

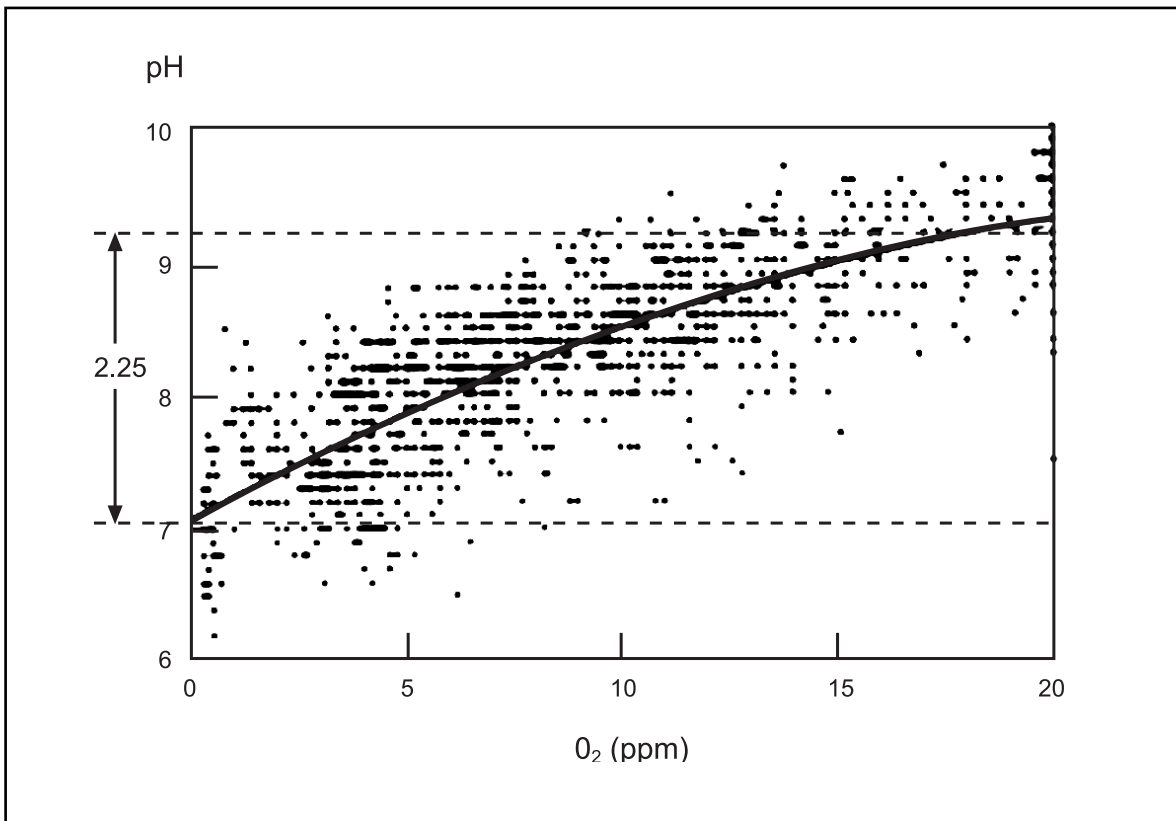


Figure 3. Correlation between the Oxygen concentration of the flood water and pH in five flooded soils (P.A. Roger and P.M. Reddy, IRRI 1996 unpublished from Roger 1996).

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 ( $\text{CaCO}_3$ ) 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.

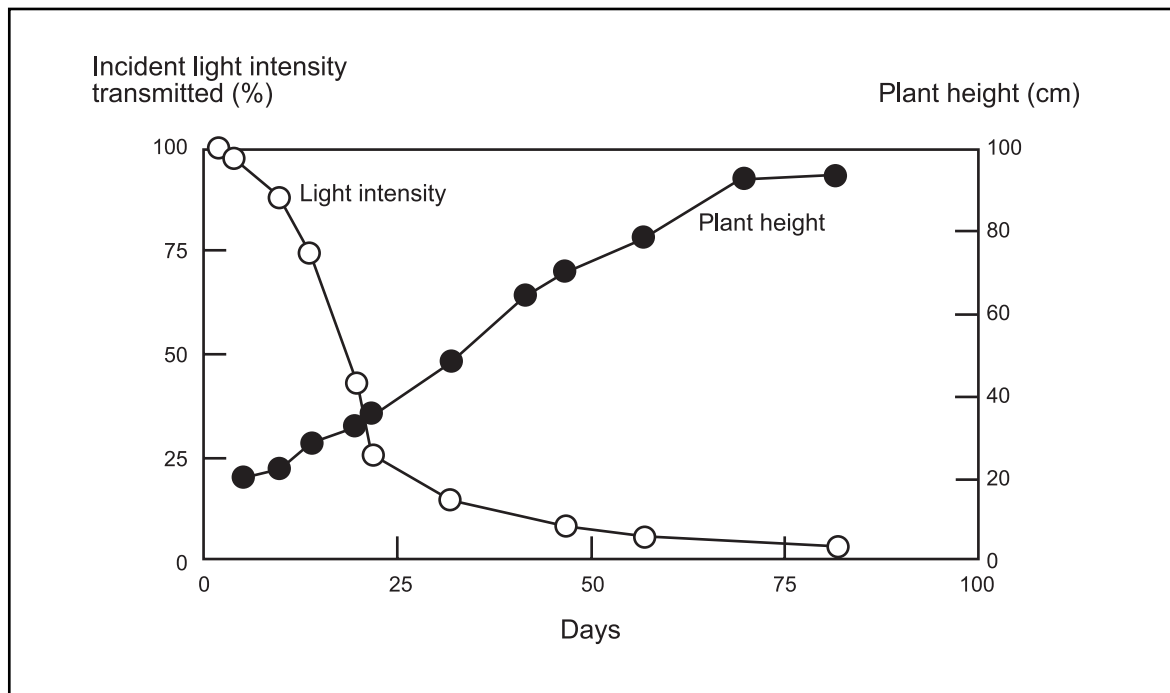


Figure 4. Relation between plant height and incident light intensity transmitted under the new canopy (Kurasawa 1956 from Roger 1996).

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 recolonisation 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  $\text{CaCO}_3$ .

Of importance to rice-fish culture is the application of nitrogen rich fertilizer such as ammonium sulphate  $[(\text{NH}_4)_2\text{SO}_4]$  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·m<sup>-2</sup>·day<sup>-1</sup>, but in most cases would range from 0.2 to 1.0 g C·m<sup>-2</sup>·day<sup>-1</sup>. 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 60 <sup>th</sup> 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.