Deep-water rice and indigenous fish co-cultivation to ensure rural livelihood, food security, and ecosystem health

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Abstract:

Access to nutritious food to an ever-growing global population becoming a challenge and the situation might worsen in the face of climate change and environmental degradation. It is largely agreed that modern agriculture requires a major overhaul in its strategy, that should tap the technological innovations from the traditional agricultural system. The key is to develop sustainable intensification methods that optimally improve efficiency gains to produce more food without using more land, water, and other inputs. Coupled rice and fish culture have been offering a viable solution at many parts of the world.

In the many parts of West Bengal and Bangladesh, a flash flood is a major problem causing havoc in villages, destroying crops, and jeopardizing livelihood. In order to circumvent the problem, in this pilot study, we have attempted to co-cultivate indigenous cat fish (*Clarias magur*) and deepwater rice landraces to examine their performance for a possible integration in flood-prone areas. The entire process was devoid of any inorganic fertilizer or chemical pesticide. In the flooded condition, out of the five landraces tested, three survived and yielded a significant amount of rice; similarly, the catfish also demonstrated promising growth and attained its maturity within the period. In 0.025 hectare of land, we obtained 53.8 kg of rice along with 43.8 kg of fish, which is promising to ascertain subsistence in the flash flood areas. At the end, we also suggest a probable extension of the proposed scheme. To our knowledge, it is the first report of integration of deepwater rice with catfish that holds potential for implementation to ensure rural livelihood, food security, and ecosystem health.

Keywords: Rice-fish culture, deep-water rice, *Clarias magur,* sustainable agriculture, food security, livelihood

Introduction:

In the twenty-first century, we are confronted with multiple severe crises. At one end, environmental degradation has been reaching its pinnacle. The rate of the world's population growth has been unprecedented and that raises serious concerns on provisioning food for all (Godfray et al. 2010). The constraining factors are the limitation of agricultural resources (land and water) to feed growing global population with the overarching effects of global climate change that consistently threatens world's food system (MacDonald 2010; Brown and Funk 2008; Piao et al. 2010). Thus, world agriculture experiencing a tremendous pressure to produce sufficient food while keeping the effects on the environment at a minimal level. Ensuring food security is thus a challenge for scientists, farmers, landholders, and policymakers alike amidst this critical situation. The problem becomes overwhelmingly acute in light of environmental degradation and associated climate change. Although industrial agriculture in last centuries has substantially intensified crop production it also incurred a huge cost in terms of degradation of soil, water, and thus damaging to human health and ruining the future resource of food production (Altieri 1998; Pingali and Roger 2012). Summarizing, it has negatively affected the ecosystem by using a high amount of chemical pesticides and fertilizers for several decades. It destroyed natural flora and faunal community inhabiting any agro-ecosystem, severely polluting soil and water, and contiguous aquatic bodies, degrading the quality of soil thus largely impairing long-term cultivation, inducing pest resistance, and increasing the cost of agriculture (Altieri 1998). Furthermore, it has not only disrupted the biological processes integral to agro-ecosystems but also abolished the indigenous seed network (Pautasso et al. 2013). It happened mostly after corporatization of agricultural sectors when lab-generated not farmer selected seeds from multinational companies entered the market, be it disease resistant, or high yielding, or fortified with other nutritional characters (Mackill and Khush 2018). It implies a fatal effect on seed sovereignty; i.e., the farmers who tend to loose their fundamental rights on their seeds (Pautasso et al. 2013; Coomes et al. 2015; Wittman et al. 2010). In view of the above discussion, it is largely agreed that modern agriculture requires a major overhaul in its strategy, that should tap the technological innovations from the traditional agricultural system and employ agricultural methods that judiciously utilize natural resources and depend on extrinsic means to a lesser extent. It would eventually minimize its effect on local ecology and environment.

Prior to industrial agriculture for many centuries and even over millennia, traditional agricultural systems have largely managed to ensure food and nutritional security of a large fraction of the global population (Altieri 2004). The traditional agricultural systems have been created, perfected, and maintained by the farmers' generation after generation harmonizing with natural elements. Moreover, because these systems are based on high species diversity, diverse species-species interactions, these agricultural systems demonstrate high resilience and adaptation to local conditions (2004; Zhu et al. 2000; Altieri and Nicholls 2004). In addition, while exercising agriculture, they have also carefully selected several culturally and economically important traits of crops and generated many unique varieties known as crop landraces. Being locally adapted, many of these landraces have been explored but reserve immense potential to be exploited for in agricultural sector.

Despite the diversity of agricultural systems, structure and functions of most traditional agroecosystems largely overlap (Gliessman 1990; Altieri and Nicholls 2004) e.g., they demonstrate high species numbers and structural diversity, dependence on full range of local micro-environments, maintenance of closed cycles of materials and waste through effective recycling practices, complex biological interdependencies, resulting in a high degree of natural pest suppression, reliance on local resources and human and animal energy, thus using low levels of external input and resulting in positive energy efficiency ratios, use of indigenous landraces of crops, wild plants, and animals. Summarizing, it hinges on sustainable systems that would be beneficial in the longer run rather offering short-term payoffs. The key is to develop sustainable intensification methods that optimally improve efficiency gains to produce more food without using more land, water, and other inputs.

Rice-fish co-culture, in a conservative sense, is a traditional method of growing 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, rather it includes aquatic animals naturally living in rice fields including freshwater prawn, crayfish, crab, turtle, bivalve, frog, and even insects. Thus, it encompasses the spirit of holistic farming of species naturally inhabiting in the rice fields. Various mixed crop-fish-livestock systems gradually receiving attention from various stakeholders that tend to enable the farmers to combine different enterprises on the farm; it is done in such manner that one influences growth of the other synergistically thus minimizing external chemical inputs and maintaining a stable production (Ahmed et al. 2007; Ahmed and Garnett, 2011; Dugan et al. 2006; Halwart and Gupta 2004).

History

The origin and early history of fish culture in rice fields are contentious. Probably, it has its root in China followed by spread over larger geographic regions of south and south-east Asia. In China, fish culture in rice fields has a long history which can be traced back to the Shang Dynasty (1401-1154 BC) (Li 1992), Eastern Han Dynasty (25-220 AD) (Guo, 1986). So, it is hypothesized that stocking of fish in rice fields had started 1700 years ago in China according to archeological and written records (Li 1992; Cai et al 1995). Clay models depicting rice fields, crucian carp, grass carp etc Han Dynasty (25 - 220 AD). The earliest record dates from the Wei Dynasty (220-265 AD) that depicts a small fish sharing similarity with common carp.

However, it is not known how it has disseminated across South and South-East Asia. One view purports that fish culture in rice fields was introduced into South-East Asia from India about 1500 years ago (Tamura, 1961; Coche, 1967; Vincke, 1979). Around 1900, rice-fish culture has been practised in Madagascar, Italy, U.S.A. (Arkansas). Rice-cum-fish culture became well established in other paddy growing countries eventually. Perhaps, fish-rice farming has been practised in Thailand more than two centuries back (Fedoruk and Leelapatra 1992). Similarly, rice-fish farming was developed in the mid-1800s in Japan and Indonesia (Kuronoma 1980; Ardiwinata 1953). An early review highlighted that it has been performed in 28 countries of six continents by the mid-1900s: Africa, Asia, Australia, Europe, North America and South America (FAO 1957). The most popular fish species was common carp followed by the Mozambique tilapia (*Oreochromis mossambicus*). Local variation fish diversity also prevailed, e.g., in Malaysia the snakeskin gouramy (*Trichogaster pectoralis*) was favored whereas Nile tilapia (*Oreochromis niloticus*) was used in Egypt. Diversity in fish spectrum has been wide with species ranging from buffalo fish (*Ictiobus cyprinellus*), the Carassius (*Carassius auratus*), milkfish (*Chanos chanos*), mullets (*Mugil* spp.), gobies (family Gobiidae), eels, murrels or snakeheads (*Channa* spp.) to different catfishes (*Clarias batrachus*), gouramy (*Trichogaster pectoralis*) and penaeid shrimps (*Penaeus* spp).

However, there is hardly any written documents on the spread of this culture. In contrast, it is likely that the culture developed independently in many places. As Coche (1967) suggested that in most countries rice-fish farming did not involve deliberate stocking of fish but the stocking density depended on what came in with the flood waters spontaneously. It implies the organisms already inhabiting rice fields or brought in by flood water is actually harvested in an informal or relatively organized manner. Many wild fish preferring rice field for reproduction have been harvested from the rice fields traditionally (Li 1988; Fernando 1993; Little et al. 1996). The natural assemblage of single or multiple species of fish and other invertebrates in rice fields inspired the people to combine fish to rice for increasing productivity (Gurung and Wagle 2005). Thus, the species cultured usually reflected what were living in the waters used to flood or irrigate the rice fields. The elaboration and creation of complex co-culture have gradually evolved over time from simpler forms in response to various extrinsic and intrinsic factors. Therefore, it is more likely that it has not spread out from one focal point but may have developed independently across multiple foci.

Rice field ecosystem

The landscape with cultivated rice field has been evolving since the origin of agriculture, perhaps the rate of change had been relatively faster during later years of agricultural diversification than initial phases. The wet rice field with its aquatic environment emulates a wetland that can be considered a successor of shallow marshes or swamps (Roger 1996; Ali 1992) which is largely influenced and maintained by farmers' activities. Over millennia, it has gradually turned into a favorable habitat of a variety of wetland species, which have successfully adapted their life cycles to the cycles of rice cultivation (Heckman, 2005). It is suggested that it could maintain its equilibrium from year to year owing to continuous farming (Heckman 1979). Due to the temporary nature of the standing water, the rich aquatic flora and fauna are transitory in nature and may have their origins in the irrigation canals and water reservoirs (Fernando 1993). On the other hand, there is still a significant number of insect larvae which are born and developed directly in the stagnant water of rice field, if the field is treated with organic manure instead of chemical pesticides.

The rice field biota constituted of a plethora of flora and fauna, 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 biomass of several tonnes of fresh weight per hectare (Roger 1996). Generally, the aquatic environment in rice fields is characterized by shallowness, wider variation in turbidity, and extensive fluctuations in temperature, pH and dissolved oxygen (DO). Various biotic elements play a vital role in rice ecosystems. A major source of dissolved oxygen in the water column is the photosynthetic activity of the aquatic plant biomass. The amount of DO is a key factor in the aquatic system since all animals consume oxygen for survival. The aquatic fauna takes part 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).

On a macro-scale, the rice fields have been a reservoir of biodiversity, perhaps the greatest of any tropical rainfed system (Halwart 2008). A study on the availability and use of aquatic biodiversity from rice-based ecosystems in Cambodia, China, Laos and Vietnam recorded 145 species of fish, 11 species of crustaceans, 15 species of molluscs, 13 species of reptiles, 11 species of amphibians, 11 species of insects and 37 species of plants directly caught or collected from the rice fields and subsequently consumed during one season (Halwart and Bartley 2005). In an earlier study by Heckman (1979), a total of 589 species of organisms in a rice field in Thailand has been recorded; of these, as many as 233 were invertebrates (excluding protozoans) representing six phyla and of which over half were arthropod species. In addition, there were 18 fish species and 10 species of reptiles and amphibians. Likewise, a comparable range of fish, snails, crabs, and larger insects were reported in Cambodia (Gregory and Guttman 1996). Large fauna like bird is also integral to rice field ecosystems (Bambaradeniya and Amerasinghe 2003). Out of more than 70 species of bird found in rice fields, only about 14 spp in Southeast Asia are known to feed on rice. In an organic field, the number of species of birds foraging and making nest is higher than chemical farms. There are several other birds like black drongos, egrets, open-billed storks, owls which feed on insects, small mammals, arthropods are also related to rice field food web. It seems from various studies that habitat heterogeneity is the lifeline of farmland biodiversity from the individual field to the whole landscape (Benton et al. 2003). For example, seed-eating birds seemed to occur in higher numbers in pastoral areas containing small patches of arable land than in pure grassland landscapes (Robinson et al. 2001); though some bird species specifically depend on the open habitats provided by farming systems in Africa (Söderström et al. 2003), in Europe (Pain and Pienkowski 1997) and Central America (Daily et al. 2001). Aquatic eco-systems also act as a refuge to many rare and threatened species. Bengal Florican, an endangered species, inhabited around the deepwater rice ecosystem and the adjacent flooded grass-lands near the Tonle Sap, Cambodia (Smith 2001). *Ichthyophys bannanicus* is an endangered amphibian found in rice fields in Yunnan, China (Luo 2005). In Sundarban region of West Bengal a turtle species *Lissemys punctata* is often inhabited in rice field (Bhupathy et al. 2014). In Burdwan district West Bengal, a large rodent (locally called *dindur* among tribal groups) inhabiting the dykes of rice-field are accepted as food by local indigenous people (Abhra Chakraborty, Pers obsn).

Rice fields happened to be a rich source of edible organisms in many areas and ensured food and nutritional security. In many Asian countries where rice is the main staple and often is accompanied by highly diverse food elements such as edible leaves or fruits of co-occurring shrubs, shrimp, crabs, shellfish and snails, rodents, turtles, frogs, and even insects and snakes. These biotas grow, forage, and reproduce in the field and caught in the wild to supplement the carbohydrate-based diet with additional nutrition. Traditionally, farmers in the rice-growing regions make judicious use of this rice field biodiversity, collecting the plants and animals and using them as an easily accessible source of protein, fatty acids and other nutrients (Choulamany 2005; Luo 2005; Meusch 2005). Many studies found edible animal taxa and leafy plants around paddy fields, e.g., Heckman (1979) reported one vegetable and 16 animal species in a single rice field in Thailand. Similar diversity has been found in other areas of Southeast Asia (Gregory 1996; Gregory and Guttman 1996). Balzer et al. (2002) observed about 90 aquatic species (excluding plants) collected from rice fields by Cambodian farmers and used daily in rural households. Such a diversity of food biota from rice fields, while still common in many areas, is reported to be decreasing (Halwart 2003). Earlier, rice-based capture supplied half of the daily consumption; in contrast, only one-fifth to one-third is derived from recent captures in rice-based farming. The quantity collected in one day nowadays is equivalent to what was collected a decade ago in one hour (Luo 2005). Likewise, Cambodian villagers have experienced reduced fish catches at household level over the past decade (Schilling 2004) and estimate that in three to five years there will not be enough fish to make a living (Balzer *et al*. 2002). Human population expansion and the resulting pressure due to over-harvesting of aquatic resources are also functional in the decline of living aquatic resources; and there are a number of concomitant factors involved: heavy and unregulated use chemical fertilizer and pesticide, destruction of fish breeding grounds, and illegal fishing tools etc. Other aquatic and semi-aquatic biotas are also negatively affected by similar human-induced modification; it renders rice field eco-systems depauperate of the great diversity that once it nurtured.

The effects of co-culture

Crop-livestock-aquatic fauna co-cultivation is a highly efficient system that employs same land to cultivate crops and other co-browsing / inhabiting animal species. It has become even more imperative when the further increment of land is not possible but agricultural production required to be intensified, especially to ensure food security in the face of climate change. However, not only using the same piece of land to produce carbohydrate and protein in a complementary manner, but it also offer some additional advantage. Thus, the significance is manifold:

1. Environmental:

A. Reduction in insect pest incidence: Fish population feed on the larvae of insects which use water to move around, it has a large impact on rice pest management (Matteson, 2000). Larvae of rice stem borer, *Chilo suppressalis,* rice green caterpillar *Naranga aenescens,* rice snout beetle *Echinocnemus squameus* and *Liburnia striatella* are the food of fish population. In addition, those which drop into the water, such as brown plant-hopper *Nilaparvata lugnes* and *Chilo simplex* are also consumed. According to experiments conducted in Jiangxi, China rice-fish culture resulted in a 53% decrease in the early damage caused by the striped rice-stem borer *Chilo suppressalis* (Yin Pi-zhen, 1983). In a recent study by Xie et al. (2011) have shown that co-culturing rice and fish has significantly reduced a suite of pests and hence lessened the pesticide application by 68%. They observed that the fish bumps into the rice stem and dislodges the insects like plant hoppers that in turn fall in the water and consumed by the fish. This caused 26% reduction in pest infestation. They have also predicted an inhibition of rice sheath blight since fish can eat up the mycelia of *Rhizoctonia solani.*

B. Fish culture in rice fields can reduce the loss of nutrients in the field. Aquatic plants along with planktons absorb nutrients and can compete with rice in nutrient procurement. While swimming and foraging, fish tends to loosen the soil, thus aerating the soil, enhancing the decomposition of organic matter and promoting the release of nutrients from the soil. In addition, the excreta of fish directly fertilize the water, therefore, the concentrations of three major elements, e.g., nitrogen, phosphorus, and potassium are shot up. Relevant here, Xie et al. (2011) have also indicated a reduced use (by 24%) of chemical fertilizers if co-culture is adopted. They reported a complementary use of nitrogen (N) between rice and fish that results in low N fertilizer application and low N release into the environment.

C. In terms of energy efficiency, rice and fish co-cultivation is a highly efficient system. It hardly requires any extrinsic input such as pesticides, or chemical fertilizers. In contrast, modern agriculture hinges on the monoculture of a crop in a homogenized landscape system is highly energy intensive with low efficiency. Whereas, the co-cultivation system exploits a complementary resource use and builds on a synergistic relationship.

D. The presence of weeds in the rice fields tends to reduce rice production as high as 50% (Coche, 1967). The weed-control by the use of herbicides causes severe environmental damage (Pingali and Roger 2012). However, it has been demonstrated that herbivorous (macrophytophagous) and algivorous (microphytophagous) fish can be successfully used in the control of weeds and algae in the rice fields (Coche, 1967; Halwart and Gupta 2004; Khumairoh et al. 2018; Xie et al. 2011). Besides, the fish population can feed on aquatic plants in various means, e.g., species of *Azolla, Salvinia, Lemna* are directly consumed, seeds of many species are also eaten up, tender parts of many plants (*Utricularia, Ceratophyllum, Najas*) are also good food for fish. Altogether, this helps to control the rate of propagation of the weedy plants (Cheng et al. 2015).

2. Economic: The co-culture improves the income status of the farmers who adopt the technology. The case of economic upliftment of the practicing farmers has not been explicitly studied, but since on the same land one can obtain two harvests simultaneously and many groups have been pursuing this over the years or decades it may be concluded to be economically viable.

3. Community nutrition and health:

A. Nutrition: Rice and fish provide both carbohydrate and protein at the same time from the same field. Therefore, it indicates the fact that farmers who culture fish in their rice fields have access to better nutrition. While rice offers carbohydrates, vitamins, and other minerals; fish could prevent protein deficiency and contribute to the improved socioeconomic welfare of populations (Coche 1967; Elvevoll and James 2000; Roos et al. 2002). For example, it is estimated that home consumption accounts for 35% of the production in Northeast Thailand (Mackay 1992). 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" has cropped up (Demaine and Halwart 2001). The nutritional contribution extends from micronutrients and proteins to essential fatty acids that are needed for visual and brain development. Aquatic animals in rice fields represent a significant source of animal protein for economically down-trodden communities who may not afford to buy animal protein from the market. They are also an auxiliary source of food security during times of rice shortages (Halwart 2008). They supply essential micronutrients that are absent in rice or found in limited quantities, particularly calcium, iron, zinc and vitamin A. However, their amount of animal food produced in inland waters and the potential is rice fields is generally underestimated, because being produced in small quantities (however collected by many individuals and in large areas) they are all locally consumed or marketed, and therefore not recorded in official statistics (Halwart 2008). As a result, information on aquatic biodiversity and the contribution these resources make to rural livelihoods, food security and nutrition is not available to and not recognized by policymakers.

B. Human health - Raising fish can offer additional health benefits since it controls two important vectors, mosquitoes, and snails. Mosquitoes are one of the greatest threat to human health and well-being and are known carriers of malaria, filaria, encephalitis, and dengue fever. Eventually, many mosquitoes tend to develop resistance of insecticides. There are a lot of studies indicating fishes in wet rice field eat mosquito larvae, therefore, reduces vector-borne diseases; e.g., field surveys in China indicated that mosquito larvae densities in rice fields with fish were only three times less than in rice fields without fish (Wang and Ni 1995). Similarly, other studies revealed that rice fields stocked with fish almost eradicated mosquito larvae population, whereas in rice fields not stocked with fish the density of mosquito larvae ranged from 32000 to $128000 \cdot ha^{-1}$. In Indonesia, fish were found to be even more efficient agent to control mosquitoes than the chemical control such as DDT. On the other hand, certain species of freshwater snails can act as hosts to trematodes (*Schistosoma* spp.) that cause schistosomiasis entering the human bloodstream. But, the effect of fish on the schistosoma-carrying snails is less clear and more studies required to establish the connection.

The rise and fall of rice-fish culture

Agricultural intensification has not only brought about an increase in yield but also multiple detrimental effect to ecology and environment. The rice field biodiversity is immensely threatened due to changing farming practices with widespread mechanization and heavy use of chemical inputs in Asia. Indiscriminate use of chemical fertilizers and pesticides greatly affect the aquatic fauna and flora including the fish. Many studies have already documented the adverse effects of industrial agriculture on edible rice field aquatic faunal diversity (Balzer *et al*. 2002; Halwart 2003; Luo 2005; Schilling 2004). Moreover, it has also greatly affected human health (Pingali and Roger 2012). Rampant application of pesticide has an adverse effect on fish culture in rice fields that often regarded as a major causal factor underlying this decline. For example, sixty-seven percent decline in paddy fish production since 1972 was attributed to increased pesticide use in Malaysia (Spiller, 1985). In addition, environmental degradation and land-use change leading to the disappearance or of permanent reservoirs (e.g., ponds, perennial aquatic bodies, narrow streams) within the vicinity of the rice fields which often served as refuges to sustain metapopulations of aquatic organisms is another factor of biotic impoverishment (Fernando et al. 1993; Gurung and Wagle 2005; Li 1988).

Worldwide survey of fish culture in rice fields:

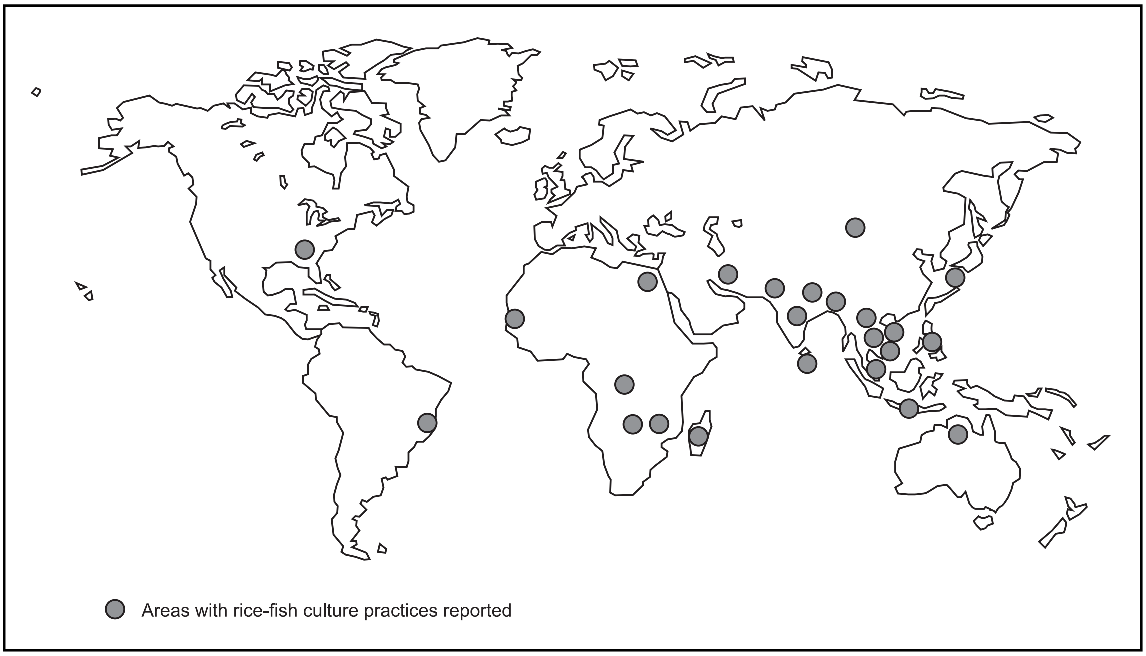

Figure - 1: The distribution of rice and fish cultivation system prevalent worldwide (source: Halwart and Gupta, 2004)

The available literature suggests rice-fish farming is still practiced in widely distant countries (figure - 1). Although no formal statistics is available in south Asia, east Asia, southeast Asian and African countries are replete with rice and fish culturing farms.

East Asia

Among the east Asian countries, China dominates in terms of antiquity, production, and technological extension. Being one of the greatest producers of rice, fish culture integrated in rice field has often given strong emphasis. The country remains one of the largest producers of aquaculture animals. Following the formation of the People's Republic of China in 1949, the rice-fish culture promoted and thus developed very rapidly. Therefore, in China rice-fish farming, largely supported by the government, is mostly encouraged as a viable option and complementing its rice production. On the contrary, it has never become very popular in Korea or Japan.

South-east Asia

Coupled rice and fish culture has been a prevalent exercise across Southeast Asia. The most notable countries in this regard are Thailand and Indonesia. Thailand is one of the places where co-culture has been practised for the last 200 years. Mostly in north-east where wild fishes are captured for stocking the rice fields which was later promoted by the fisheries department and gradually made its way to the central plain-land. Provisions of fish seeds and technology helped its popularization and growth. However, with the advent of HYV chemical inputs in the field caused a near-crash of the system in many parts around the 1970s. However, rice-fish farming has not disappeared completely but it has been revived in recent years, particularly in the central plains, north and northeast Regions. Likewise, around Javan Island of Indonesia fish are stoked with rice and cultivated for centuries. The dissemination of culture outside its place of origin is attributed to the governing system as well as to Dutch administrators. It was considered as fallow-season crop and emerged as an additional source of income for landless tenants. Later, from the middle of the twentieth century there has been an upsurge in fish production with a decline in 1977 owing to 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 (Koesoemadinata and Costa-Pierce 1992). However, in recent years the farming has gathered its pace and has been practiced in 17 out of 27 provinces in Indonesia. In other Southeast Asian countries, Malaysia, Vietnam, and Philippines nurtured the strong tradition of aquaculture in rice fields. Not entirely restricted to fish cultivation, it also involved catching wild fish or shrimp naturally inhabited rice fields. However, these countries are facing a gradual decline in recent years because of various reasons.

South Asia

Among South Asian countries, peoples of India and Bangladesh have been actively participating in fish culture in rice fields. India, one of the largest producers of rice, has a long tradition of catching small aquatic animals including fish from the inundated paddy fields. Areas of West Bengal where inundated paddy fields were traditionally used as a breeding ground of air-breathing fishes and other aquatic fauna (e.g., shrimp). Therefore, it constituted a significant part of their diet. There are other examples of formalization of this age-old technique, e.g., Pokkhali in Kerala or in terraced rice fields of Apatanis; but it is limited to capture systems in the Ganges and Brahmaputra plains. Similar culture has also been observed in riverine rice ecosystems of Bangladesh. Bangladesh is one of the few countries continuously encouraging farmers with active support from research and development wing and NGO intervention. A large number of Bangladeshi farmers have experimented and have honed up practices to suit their own farming systems.

Apart from Asian countries, different countries from Africa (Nigeria, Egypt, Zambia, Madagascar, and others), Europe (Italy, Hungary, Russia), South America (Brazil), United States have also experimented and succeeded to commercialize to a varying rate.

India

In the deltaic regions of West Bengal and in Kerala, fishes are cultivated in rice fields.

In **West Bengal**, the schedule starts from February-March, when tidal water is drawn into the canals of the rice fields, at high tide; in April-May, young fish enter the field; with the onset of the monsoon, the fields are prepared for salt-tolerant rice followed by transplantation of the seedlings in

July; in August, fish are admitted in the rice and the depth of water is progressively raised, sometimes as high as 60 cm; the fields are drained and the fish find a refuge in the canals where they are captured in October-November; finally the rice is harvested between November and January. The fish crop consists mainly of species belonging to the genera Asian sea bass (*Lates calcarifer, Parshe* (*Chelon parsia*) and Tengra (*Mystus tengara*)*,* Artamim (*Sperata aor*) and the average yield ranges between 100 and 200 kg/ha. In Purulia district, paddy fields are arranged step by step like staircases. The fields were guarded with broad dykes to maintain water table. *Magur* (*Clarius magur*) used to breed and spawns are developed in the water within 10 to 12 days. Water flows from the upper portion to the field to the lower through narrow channel situated at the dyke, and *Magur* spawns move with the water. Fishermen often set a box shaped bamboo basket (locally called *Ghuni*) at the mouth of those channels to collect the seedling. In Jhalda block of Purulia district, mature *Koi (Anabus testudineus), Magur* are kept in the pond adjacent to the paddy field. When mature *Magur* or *Koi* migrate to the paddy field for breeding, and seedlings are collected from the paddy fields. In Sunderbans of south 24 Parganas, breeding of *Singhi (Heteropneustes fossilis), Magur, Koi* in the inundated paddy fields is a common phenomenon. During monsoon mature *Magur, Singhi, Koi* or *Lata* migrate from pond, shallow wetlands & *nayanjuli* (rivulet), to the inundated paddy field for breeding, and seedlings are collected from paddy field by means of *Ghuni* or Bamboo basket.

Kerala - Fish culture in brackish water rice fields in Kerala is different from West Bengal. The low lying paddy fields are called ‘Pokkali’. The ‘Pokkali’ fields of Kerala are usually single crop paddy fields grown during the Monsoon period, extending to 10,000 acres and yielding an annual production of 5,000 tons. After harvest of paddy, fields are usually used to trap high tide water along with prawn fry mainly through sluices followed by allowing the water to let out through the net screen during low tide; thus it is known as the paddy field prawn filtration. Every subsequent high tide during the autumn the prawn fry are trapped, and often a kerosene oil lamp is hung on the sluice gate believed to ‘attract’ prawn fry. The stocked prawns grow in the ponds until December; they are harvested from December to April. Paddy is usually cultivated in these fields during July - September when the brackish water surrounding the paddy fields are low in salinity after heavy South-western Monsoon showers. Sometimes prawns are trapped and caught without allowing a growing phase for prawns, while in others the trapped prawns and fishes are cultured which offers better yields.

Our project: Culture of indigenous catfish (*Clarias magur*) in rice growing in deep water

A. Indigenous catfish - *Clarias magur*

There are multiple species of *Clarias* (family: Clariidae) found in India and *Clarias magur* (henceforth *magur*) is widely distributed across the Ganga and Brahmaputra river basins in eastern, northern and northeastern India, Nepal, Bhutan, and Bangladesh (Ng and Kottelat 2008). Its native range includes Bangladesh; central, eastern, northern, and north-eastern states of India (Arunachal Pradesh, Assam, Bihar, Chandigarh, Chattisgarh, Haryana, Himachal Pradesh, Jharkand, Madhya Pradesh, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim, Tripura, Uttaranchal, Uttar Pradesh, West Bengal); Nepal. *Magur* inhabits ponds, rivers, and other aquatic bodies; they are commonly found in fresh as well as brackish water, and they can exist in cloudy, low-oxygen waters. In the mud and swampy waters, they lie concealed for hours as it bears special accessory respiratory organ. Because of the same organ, it can live out of water for quite some time and move short distances during the water scarcity, especially during drier seasons.

It is an omnivore and is mainly active at night and prey on items such as insect larvae, fish eggs, fish and occasionally plant material. *Magur* attains maturity within the first years of life and normally spawns from April to August in both open and confined waters (Ahmed *et al.* 1985; Bhuiyan 1964; Bhuiyan et al. 1992; Chowdhury 1981). Talwar and Jhingran (1991) reported, that the *C. batrachus* spawn for short period just from July to August. In Southeast Asia *C. magur* generally spawn during the rainy season, when rivers rise and fish are able to excavate nests in submerged mud banks and dykes of flooded rice fields. It breeds in shallow marginal waters of ponds, ditches and natural depressions, and inundated paddy-fields during summer monsoon and rainy season and attains a maximum length of 35 cm and a weight of 250 g (Chowdhury 1981). Locally known as *Magur* in West Bengal and Bangladesh, it is a fish of great demand and attracts high market value. Its popularity is due to its use as an important part of the diet for children and lactating mothers and also prescribed as the diet for the convalescent of the patients. This fish is highly regarded for food due to its high protein (15.0%), low fat (1.0%) and high iron content (710mg/100g tissue). But, *magur* is highly prized fish that is threatened due to over-harvesting. Conversion of wetlands and indiscriminate application of pesticides and chemical fertilizers has shrunk its breeding grounds. After Green Revolution, application of the pesticides in paddy field has increased manyfold causing a mass destruction of breeding ground of several fish species, which breed in inundated paddy fields. Other sources of threat stem from the introduction of the Thai catfish. The population in the wild has declined more than 50% in the last few years and its predicted decline at the same or slightly higher rate throughout the species range qualify it as in the endangered category.

B. Deep water rice

Rice grown in deepwater is an important staple food crop several million hectares of Asia and West Africa. It is mainly cultivated in the river basins of the Ganges-Brahmaputra of India and Bangladesh, the Irrawaddy of Burma, the Mekong of Vietnam and Cambodia, and the Chao Phraya of Thailand. Some are also found in the upper and middle basins of the Niger River in West Africa. Deepwater rice is ingrained in the cultures of the south and south-east Asia where mighty rivers overflow and inundate cultivated fields in rainy season; thus causing a flash flood or prolonged water-logging condition. The obvious outcome is a huge crop damage leading to economic instability and food insecurity of the smallholding farmers.

Deep water rice landraces are a specific group mostly cultivated across south and south-east Asia, where usually flooding deeper than 50 cm for 1 month or even longer during the growing season. So, by definition, the group includes all landraces of rice adapted to water deeper than 50 cm. At depths of 50-100 cm, the plant survives by their tall stature and long leaves and are called 'traditional talls'. The floating rice usually start at a water depth of 1 m and survive primarily by their elongation ability. Apart from elongation, floating rice have two unique adaptations that enable them sustaining in deep water: one, the ability to develop nodal tillers and roots from upper nodes under the water, and the upward bending of the terminal parts of the plant, called kneeing, which keeps the reproductive organs above water as the floodwater recedes. There is a continuum of rices adapted to variable water depths from the rain-fed lowlands and tidal swamps to the deep-water and floating rice. Most deepwater rice landraces are susceptible to complete submergence, which causes a rapid consumption of accumulated starch and inhibits protein hydrolysis.

There are three major types of deepwater rice cultivated in Bangladesh: 1) Typical deepwater rice, 2) *Bhadoia/Ashwina* and 3) *Rayada* (Bashar et al. 2004; Catling 1993; Perez and Nasiruddin 1974). They all are collectively considered as deepwater rice and share similar elongation capacity after rising flood water level, kernel color, and yield. However, *Rayada* rice, endemic landraces of Bangladesh, is unique in several characters. *Rayadas* seems to be most primitive and share some features with wild rice (Khush 1997). On the other hand, *Ashwina/Bhadoia* are almost similar to typical deepwater rice except being little or no photoperiod sensitivity (Bashar et al. 2004). They derive their names from Bengali calendar months of *Bhadra/Ashwin* (August/September) when they usually flower (Haque 1974).

The origin and diversification of deep-water rice are not known. It can be logically surmised that the cultivation of deepwater rice likely emerged as an adaptive reciprocation to minimize the detrimental effects of flooding. Perhaps, farmers have long recognized the devastating effects of flood and undergone multiple spells of crop loss and experienced food insecurity. Therefore, they initiated exploitation semi-aquatic wild rice that can withstand shorter to long-term flood. This eventually allowed them to artificially select a founder population and finally domestication.

C. Objectives:

There is a large body of literature that investigated various aspects of fish culture in inundated paddy field. These have broadly revealed that rice plants performed relatively better when coupled with fish. Keeping it in view, our aim, in this project, is manifold. 1. To combine cultivation of deep-water rice landraces with fish to achieve a sustainable mode of agriculture, deep-water rice is a major ecotype(s) of rice in flooded eco-system of south Asia, so the ; 2. To test whether *magur* can be bred in a rice field ecosystem; it has two-fold implications, application of pesticide has caused massive destruction of their breeding ground leading to dwindling of population, *magur* is one of such species. So, culturing this species would enable us to raise variable population that can be simultaneously employed for their breeding, conservation and maintenance of this endangered species.

D. Experiments:

a. Materials and Methods:

Field preparation: The first step of deep-water rice and fish co-cultivation was to dig up a pond to store and harvest rain-water (figure - 2a). The length of the pond was about 60ft and width was about 34ft and the pond was dug in such a manner that the depth increases gradually from 2ft at one end of the pond to 10ft at the other end (figure - 2b). This was done to emulate the cultivation of deep-water rice in a naturally flooded condition. Except this, there is no other organized preparation of field such as plowing, weeding, bed preparation, spraying of fertilizers, or transplanting. Therefore, the only period which required intense labor was broadcasting and manuring of seeds; since digging of pond was accomplished with the help of earth-movers. Following this, no other phase demanded manual labor. This renders the cultivation technique a very simplistic, straightforward, and relatively less labor-intensive. A gross timeline for various activities for a cultivation season is shown in Table -1.

Figure 2: a,b. Digging of the pond and preparation of the land; c,d. *Magur* fry; e. Azolla as fish-feed; f. Fencing of the pond. Figure 2: a. Initiation of germination, b-e. Growth-stages of rice plant keeping pace with water table rise; f. Onset of flowering; g; Mature plant before harvest; h. Mature *Magur;* i. Adventitious roots from the submerged part of the plant; j. Golden harvest

Soil type, water composition and preparation: The soil was alluvial and the pH was measured prior to experiments. Water pH was measured by pH paper (Merck) twice (morning and evening) on a specific date of every month.

Collection of seeds: Rice seeds were collected from Richharia conservation center, Ausgram, Burdwan district, West Bengal. Seeds of five different deep-water landraces (namely *Hormanona, Jaldhapa, Kaliray, Kumrogore, Sadajabra*) were chosen on the basis of varying capacity to sustain water-logged condition.

Fish stocking rate and feed: Healthy *magur* seeds were collected from a private hatchery (figure 2c-d). We stocked around 500 fries of *magur* in the water, i.e., approximately two fries per m^2 was liberated in the 1^{st} week of July. Their average length was eye-estimated and weight was measured. Formulated pelleted catfish feed (total 50 kg with 40% protein applied in eight months, every day an average of 100-150 gm per day) was applied. In addition, Azolla was also provided as fish feed fortnightly (figure - 2e).

The cultivation cycle: The cultivation cycle started as the pond was gradually filled up with the rain water during early June. With the onset of first showers, ten feet depth was filled up to the 3 feet within the 1^{st} week of June. During the 3rd week of June, when water was filled up to 1 ft at the 7 ft depth of the pond broadcasting began at a rate of about 30 gm dry seeds / 36 ft^2 . The seeds were broadcasted on the wet soil for germination in seven consecutive rows at two depths, i.e., 3ft and 5ft. Subsequently, the seeds were unevenly covered with moist farmyard manure. The water filled pond was pond fenced sub (figure - 2f). At that point of time the water level at 7ft and 10ft were 1ft and 4ft respectively. An efficient bio-fertilizer *Azolla* was applied to the pond water which served dual purpose, as a fish feed and as an organic fertilizer. It was initially applied in the first week of August followed by fortnightly application. In the next few months, with the continued rain, the water table in the pond gradually rose. In effect, rice seedling continued their growth responding to the water level rise.

Harvesting: In the first week of November, viable rice plants were harvested. After harvest, the following measurements were recorded for all the landraces: length of the submerged portion of culm, number of the submerged node, number of the root bearing node, length of the longest root from node. Fully mature fishes were finally harvested at the end of the February when water was present only in the 7 ft and 10 ft depth of the pond.

Measurement: Various biometric observations (different morphological features, e.g., tiller, grain weight, filling, pest incidence) were recorded visually for rice. Similarly, fish yield was measured in terms of body length and weight. The gain in body weight was determined taking a sample of ten random individuals following the equation: gain in weight [g/day] = F(Final weight - Initial weight) / culture period (days).

Calculation of cost and income: The details of costs, i.e., fixed (50 pair of mature *magur* for breeding) and variable operational costs (monsoon rice in 0.67 ha, fish culture, *magur* breeding) were recorded. Similarly, income from various produce (rice, mature fish, and hay) was also noted. Finally, net profit (income - cost) of this rice-fish cultivation system is calculated.

Table 1: A broad timeline of various activities during the project.

April-May	June	July	August-September	October	November
• Digging of pond • Preparation of seed bed	Broadcastin g of seeds after showers	• Seed germination • Rise of water table • Growth of seedling responding to increasing water depth	• Continued rise of water table • Continued growth of seedling with increasing water depth • Leaves of the seedlings always stay above water table	• Flowering initiation • Grain filling started • Panicles turning heavier and bulkier • Reaching maturity	Harvesting by 1st week

b. Results

Soil and water characteristics: The average soil pH was 6.8 with morning and evening pH ranged 6.8 - 6.9 and 6.9 - 7.1 respectively. Water remain turbid throughout the culture period and plankton growth was found to be minimal.

Growth and survival of rice plants: i. *Germination*: After 8-10 days, the rice seeds of all the landraces commenced germinating at both 3ft and 5ft depth (figure 3a) ii. *Post-germination growth*: the growth of the seedlings continued keeping up with the rise in the water level of the pond in the following months (figure 3b). When rice seedlings were 15 cm tall water reached 5ft depth the pond in the 1st week of July. The plant leaves elongate to avoid submergence with the increase in water depth. Near third week, water depth reached almost 2ft at a 5ft depth of the pond and rice leaves stayed well above the water surface. The seedlings exhibited growth at a steady rate responding to water level rise. It was evident from an interesting phenomenon; after a heavy 1-day shower water level increased by 10 cm, only seedlings of *Sadajabra* (at 3ft) was below water level demonstrated a rapid growth of 10 cm. In other words, to keep pace with the rising water, they grew from 30 cm to approximately 40 cm in a day (figure - 3c). After the sixth week, (10th August) water depth at 3ft and 5ft were 3.25 ft and 5.5 ft respectively. Except a few (50%) plants of *Jaaldhapa* and nearly 80% of *Lakkhidighaal* and *Hormanona* no other landrace survived at 5.5 ft. The surviving plants maintained apical part above water level. In contrast, all seven varieties survived at 3.25ft depth. In the next few months, the growth of plants continued with the continued rain (figure - 3d-e). iii. *Flowering*: After about 10 weeks, we have observed the rice plants to initiate flowering. *Jaaldhapa* flowered relatively earlier than other landraces which began to flower within two weeks (figure - 3f). iv. *Grain filling and maturation*: Around 15th October, grain filling began in a majority of the plants. As usual, most of the panicles were held above water level. Rice plants with heavy panicles attained maturity by the first week of November and were ready for harvesting (figure - 3g).

The yield of rice and fish: Among the landraces, *Kumrogore, Kaliray, Sadajabra* outperformed others, their yield were 800 gm/ 36 sqft, 900 gm/ 36 sqft, and 850 gm/ 36 sqft. *Jaaldhapa* plants that survived produced very little grains, approximately 200 gm/ 36 sqft. The calculated total yield was 53.8 Kg. In 0.025 Ha of land 43.8 Kg *magur* was produced in eight months. The average length of the full-grown *magur* was 20 cm and it weighed 100 - 125 gm (figure - 3h). The landraces varied in their response to water level and that has been manifested through their differential phenotype change (Table - 2) (figure - 3i). Throughout the life cycle of rice plants, we have not observed any pest attack in either of the varieties and obtained relatively pest-free harvest (figure - 3j).

Table 2 - phenotypic measurements of selected landraces after harvest.

Name of the Varieties	Tiller number	100 grain weight (gm)	Grain length (cm)	Panicle length (cm)	Panicle weight (gm)	Number of tiller with panicle	Length of the submerged portion of culm (cm)	Number of submerged node	Number of root bearing node	Length of the longest root from node (cm)
Harmanona	8.75	2.754	0.79	21.5	-	6.2	142	11	11	34
Jaldhapa	9.05	2.02	0.81	26.075	2.7	7.05	142	11	11	37
Kaliray	9.55	2.654	0.92	24.5	-	8.15	76	7	7	25
Kumrogore	7.2	3.3	0.94	22.725	-	5.2	76	6	7	20
Sadajabra	9.85	2.18	0.88	27.65	3.3	6.55	76	9	9	30

Table 3 - An approximate expenditure and income generation that might incur in execution of the project (for a season that lasted for eight months in 1 hectare).*					
		Item		**Rate (INR/ quantity)**	**Amount (INR)**
Cost [annual investment]	Fixed Capital Cost	Digging of pond or canal within the land**	L.S.		100,000
	Variable Operational Cost	For monsoon Rice in 1 ha. (Through Direct Sowing)	For Sowing	1 man-day @ INR 200/Man Day	7000
			For cutting	34 man-days @ INR 200/Man Day	
		For Magur Culture:	Fry: 20,000Nos	INR.60,000 (@ INR 3/Fry)	1,40,000
			Fish Feed: 2000Kg	INR 80,000 (@INR 40/Kg)	
		For Azolla Culture	L S		1000
Total costs					2,57,000
Income [annual turnover]		Paddy	2700Kg	INR 12/Kg	Rs.32,400
		Hay	8100Kg	INR 1.5/Kg	Rs.12,150
		Fish	1750Kg	INR 350/Kg#	Rs 6,12,500
Total Income					6,77,300
Gross Profit [income-cost]					4,20,300

* The table is to show the rough estimation of cost and income. The cost and income has been calculated on the basis of a one hectare plot. We have considered the landrace that offered highest yield among five and calculated the same.
** The cost of digging is an approximate value and may vary from place to place.
# Magur is a costly and highly valued fish that fetches premium price in the market, but mass production may bring down the price.

Although no data has been collected, red sorghum has been planted along the dyke that attained a height of 7-8 ft at maturity and produced healthy panicles. It indicates a possible integration of the crop along with rice-fish cultivation in the main field.

Cost and income from the cultivation: Table - 3 summarizes an approximate cost and income that the undertaken study have incurred extrapolating it for one hectare plot and stable *magur* price. The cost would arise from two major heads, i.e., fixed and variable operational costs that sum up to INR 2,57,000. Whereas, it may generate income at the tune of INR 6,77,300 through selling not only paddy and fish, but also selling hay and fish seeds. Hence, the final profit may be around INR (6,77,300 - 2,57,000) = 4,20,300 for a hectare of land.

c. Discussion

At the beginning of the 21st century, we are confronted with the global crisis of food insecurity with limited potential solutions at our disposal. It has been predicted by scientists that the produce from the existing agricultural land will not be sufficient to alleviate global hunger and we need more land to keep pace with the growing population (Godfray et al. 2010). While the quantum of arable land on this earth is finite and can hardly be extended; the emerging solution would be to develop sustainable methods that optimally intensify food production without demanding more land, water, and other inputs. It would also embrace the principles of agro-ecology founded on sustainable utilization of resources and enables energy-efficient agricultural practice that offers long term economic and environmental benefits (Altieri 2004; Gliessman 1990).

The age-old art of co-cultivation that integrates two or more organisms in the same agricultural land in such a way that they can demonstrate simultaneous growth; and may complement each other synergistically. Altogether, it proffers multiple tangible and intangible benefits. In terms of environmental impact, its ecological footprints are minimal since the process is completely organic; it does not demand any other external input of chemical fertilizers, pesticides, fungicides that renders the process environment-friendly. In addition, it also allows relatively sustainable agricultural practice than high-input industrial agriculture as the cultivation relies on intrinsic resources and makes use of locally adapted crop landraces. Moreover, the dependence between two organisms helps stimulate each others growth and development by mutually beneficial physiological processes. On the other hand, it reserves the potential to strengthen rural livelihood which can be replicated across various communities and culture. Employing the same piece of land, it produces carbohydrate as well as protein, two essential components of our diet. Apart from subsistence farming to feed farmers' families, extra harvest may also be sold to generate additional income given the production of fish and rice.

In our study, we have combined the cultivation of deep-water rice landraces of Bengal with an indigenous species of catfish. It entirely dwelt on autochthonous resources that have been locally adapted to agro-ecological and climatic condition. It takes account of their ancestral ecological condition where they have originated and evolved so that our choice exploited locally available genetic resources. We have obtained rice yield at the tune of 53.8 kg which is promising given the fact but no modern HYV can survive in the one-meter depth of water for more than a month. So, in flooded field deepwater rice and fish system is far better than any HYV; the better yield of rice when coupled with fish has been overly documented in recent years, our findings underscore the same fact (Gurung and Wagle, 2005; Tsuruta et al. 2011; Ahmed and Garnett, 2011). Apart from rice production, the simultaneous yield of *magur* was also promising. *Magur,* a highly appreciated key catfish across eastern, and central and southeastern parts of India, and its production fetches a high market price. In 0.025 Ha of land 43.8 Kg *magur* was produced in eight months. When fries were liberated the average length was 5 cm, an individual attained 20 cm in length and 100-125 gm in weight at the time of harvest. It clearly suggested that *magur* can grow well in inundated paddy field and can bring additional profit when co-cultivated with deep-water rice. Therefore, inundated paddy field can be successfully used for both of their culture, stocking, and breeding which has not been explicitly reported previously. Another important fact lies in its long-term benefits, the entire pilot study has been performed with no chemical input. The organically produced indigenous rice is healthier than rice produced with heavy-dose of chemical fertilizer. Similarly, native catfish is nutritionally superior and contains many essential amino acids and macro/micronutrients. Although we have not quantitatively measured the effect of fish on pest incidence and its contribution in yield loss in rice, the findings from a plethora of studies demonstrate that fishes feed on insect pests, either larval stage or juveniles (Halwart and Gupta 2004). Some fish species contribute to the biological control of rice pests such as apple snails, stemborers, or caseworms (Halwart 2008). In recent years, it was shown to cause a significant reduction in pest infestation (Xie et al. 2011; Khumairoh et al. 2018). Although not formally quantified we have observed that the larvae of few aquatic insects were consumed by fishes. Pertinently, researchers have also reported the suppression of weeds by a combined use of loach and *Azolla* without agro-chemicals (Cheng et al. 2015).

However, during the last part of 20th century, a more organized attempt has been undertaken at various level across various districts of West Bengal (Nadia, South 24 Parganas) and Odisha, and Kerala to popularize this culture as mean to empower rural people. The system of fish culture in paddy fields varied greatly depending upon the season, location of the plot, terrain, and the species of fish / prawn / other animals. Among various systems, the synchronous, sequential, and synchronous/sequential system have been implemented in West Bengal and met with moderate success. An experimental in Rahara, West Bengal 1.02 ha paddy plot with 0.27 ha perimeter canal was stocked with carp fingerlings at a rate of 6000/ha, in species ratio of 3:4:3 (Rohu: Catla: Mrigal) providing artificial diet of rice bran and mustard oil cake mix (1:1). Jaladhi-2 and Ratna paddy were cultivated during *kharif* and *rabi* season, respectively. It produced 1200 Kg/ha kharif paddy and 4300 Kg/ha rabi paddy besides 700 Kg fish/ha in 10 months. During 1958, *Oreochronus mossambica* and *Cyprinus carpio* were stocked in the rice plots of Central Rice Research Institute, Cuttack at a rate of 2500/ha. The yield was 77 Kg / ha in three months comprising 40% Tilapia. During 1977, a *masuri* rice field (0.16 ha) was stocked with carps @ 6000 / ha with species ratio of 5:3:2 (common carp : *Mrigal*: Rohu). The overall recovery after two months was 34%. Two plots of CR- 1014 tall variety rice gave an average yield of 76.2 Kg / ha of common carp when stocked and reared at a rate 7250 / ha for 119 days. The paddy yield was 2719 Kg / ha. In Canning of South 24 Parganas, West Bengal 0.015 ha paddy field with 20 cm dyke and 1 m deep and 1m wide trench on one side of each plot were used for paddy cum fish / prawn culture. In sequential system stocking of *Penaeus monodon* juvenile and *Lates persia* fry was done at a rate of 20000 - 25000 / ha. After rearing them for three months with tidal water, the production of 400 to 600 Kg / ha obtained (with 60% prawn). After desalinization process, the synchronous type fresh water aquaculture was continued. In this phase carp fingerling (10 gm. each) and *M. rosenbargi* Juvenile (3 gm each) were stocked @ 25000/ha in the ratio of 2:3 (fish : prawn). The yield of freshwater aquaculture was 500-600 Kg / ha in three months with 40% prawn. The paddy yield also improved (3 ton / ha) from a traditional yield of 2.6 to 2.7 ton / ha (Banerjee, 1986). Summarizing, it implied successful implementation of co-culture with varying combination of rice and fish. But very limited initiatives have been taken with deep water rice; however, once such study performed detail investigation with rice and fish with different fish feed. It demonstrated a higher production of rice when coupled with fish than monocropping (Anon 2018). Furthermore, deepwater rice with fish and poultry manure outperformed others in terms of production. In our pilot study, we have harvested 53.8 kg of paddy and 43.8 kg of fish from 0.025 ha of land. The total profit translated to 4,20,300 INR (table - 3), an amount quite encouraging to rural communities. However, the price of agricultural produce is highly dynamic in local wholesale market and may vary even greatly when supply is plentiful; e.g., *magur* is a costly fish species, the supply fall short of its demand and its rarity adds to its cost, but mass production of *magur* may bring down the high market price. In the year of 1987-1990, Agricultural dept. of West Bengal Govt. carried out a trial of co-culture of rice and fish in seven places of four districts, including on farm and in experimental station. They successfully executed the project and received a yield of 4.1 tonne / hectare, the quantity is comparable to the HYVs, e.g., MTU 7029 or *Lalswarna* or even better in places than commonly cultivated HYVs. Unfortunately, the practice of co-culture as a sustainable way of gaining better yield has not been adopted and implemented at a wider scale.

Rice and fish cultivation has been very productive and accepted system in China and other south-east Asian countries in recent times. Studies in China document that, apart from yield increase and income generation, the rice fish system has reduced pest attack, fertilizer and pesticide application (Hu et al. 2016; Xie et al. 2011). In Bangladesh, a recent study offered strong evidence of that integrated farming systems such as rice-fish can play a key role in enhanced food production and singled it out to be a better alternative than monoculture in terms of resource utilization, diversity, productivity, and both the quality and quantity of the food produced (Ahmed and Garnett 2011). In Indonesian districts, researchers combined (*Oryza sativa*, var. Ciherang), azolla (*A. microphylla*), fish (*Oriochromis nilotichus*), ducks (Anas *Platyrhynchos javanicus*) and border plants on the ridges. They demonstrate that the system is climate-resilient and enable controlling weeds and pests in unfavorable weather conditions, thus relatively robust compared to other rice systems. The stable and reliable yields across different locations suggest that the design is scalable and replicable and invoke a prioritization (Khumairoh et al. 2018).

The socio-cultural history of informal fishing in temporarily flooded fields revealed a natural biological association between rice landraces in flooded fields and many native species of fish, arthropods, mammals. The formal and organized co-agriculture actually emulates and extends this long-nurtured traditional agro-ecological knowledge acquired by local communities several centuries back. Its origin remains untraceable, both single origin in China followed by spread over countries and multiple distinct origins China and at flood-bed rice growing regions of south Asia are equally likely. Historical texts suggest that various air-breathing fishes, e.g., *Singhi* (*Heteropneustes fossilis*)*, Magur* (*Clarias spp*)*, Koi* (*Anabus testudineus*) used to migrate to inundated paddy fields from adjacent aquatic bodies during rainy seasons. Monsoon showers usually created a network of linked water channels which otherwise remained disjunct during drier seasons. This has been quite a prevalent phenomena in eastern India and Bangladesh where flooding of rice fields has been recurrent. Intuitively, the inhabitants living amidst the landscape imbibed this observation, assimilated in their traditional knowledge systems, and used their skills to harvest fishes from the paddy fields using various traditional fishing gears made up of bamboos or canes. It is highly likely that primary observation may have served as a primer that sparked further exploitation and finally diversification of fish-rice co-culture in the Indian subcontinent.

E. Recommendations for further extension and alteration

Our study demonstrates a specific type of integration to suit the demand of flood-prone agro-ecosystems that is exposed to prolonged standing water. Summarizing, this can contribute to reducing smallholder risks, while maintaining rice productivity and yield stability to safeguard national food security under climate change. The kind of integration may be broadly implemented to any deep-water agro-ecosystems, depending upon the local condition. Nevertheless, the systems of culture of fish in paddy fields may vary greatly depending upon the season, location of the plot, terrain, species of fish / prawn, and the types of landraces etc. Interchangeability of crop landraces and co-cultured animals may be possible according to the adaptability of the organisms, e.g., duck can replace catfish or other wet rice landraces may replace deep water types depending on water availability. There are success stories coupling rice and duck, rice and loach, rice, loach and azolla (Khumairoh et al. 2018; Zheng et al. 2014). Almost all of these can stimulate synergistic growth, enable nutrient cycling, and result in a better harvest than a monoculture of rice.

The current pilot project can also be modified as well extended by considering several minor amendments, i) current two-tier cultivation can be elaborated into 3-4 tier cultivation by careful design and selection of crops package, e.g., along the border on the dyke low water requiring crops such as millets (*Pennisetum* or *Elusine*), *Cajanus cajan,* or Cucurbitaceous members (such as gourd, ridge-gourd, cucumber) can be grown; ii) a small pond with an established connection with the rice-growing pond can be dug to rear and breed catfish spawns, so that fishes migrate to the pond for breeding when water overflows during the monsoon. In addition, it will also maintain continuous supply of catfish for stocking rice field and excess spawns could be sold; iii) above the fish-stocking pond ducks can also be raised forming a stable structure, so that duck droppings fall on the pond and fortify the water with nitrogen, and if the same water enters the rice field during heavy showers, rice plants would receive nitrogen without exogenous nitrogen; iv) In coastal or near-coastal belts, if some salinity tolerant indigenous paddy varieties i.e. *Talmugur, Matla, Hamilton, Kaggabath, Nonabokra* (they may tolerate soil salinity 8 – 10 mmhos / cm) is cultivated (as in sequential / synchronous type of co-culture) the total desalinization problem can be avoided. By using those varieties, more saline area where total desalinization is not possible through monsoon rain can be brought under integrated paddy cum fish culture; v) In order to employ the same field year around for growing multiple crops seasonally, it can be used to cultivate various

Rabi crops (e.g., *Bodo* rice, seasonal vegetables, winter pulses) following deepwater rice harvest in autumn. Thus, it enables the farmers to grow various crops throughout the year using the same piece of land.

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Reference:

Ahmed K, Mustafa G, Ali S, Shahjahan M. 1985. Induced Spawning of Magur Fish, *Clarias batrachus* (Linnaeus) by Stripping Method in Plastic Bowl Hatchery. *Bangladesh Journal of Zoology* 13(1): 19-24.

Ahmed N, Wahab M A, Thilsted S H. 2007. Integrated aquaculture-agriculture systems in Bangladesh: potential for sustainable livelihoods and nutritional security of the rural poor. *Aquaculture Asia* 12(1): 14–22.

Ahmed N, Garnett ST.2011. Integrated rice-fish farming in Bangladesh: meeting the challenges of food security. *Food Security 3*(1):pp.81-92.

Ali AB. 1992. Rice-fish farming in Malaysia: past, present and future p. 69-76. *In* De CR, Cruz la, Lightfoot C, Costa-, Pierce BA, CarangalandVR, Bimbao MP, ed. *Rice- fish research and development in Asia.* ICLARM Conf. Proc. 24: p. 457

Ali AB. 1998. Rice agroecosystem and the maintenance of biodiversity p. 25-36. *In* Nashriyak BM, Ho NK, Ismael BS, Ali AB, Lun KY ed. *Rice agroecosystem of the Muda Irrigation Scheme, Malaysia. Mintmada Malaysia* p. 250.

Altieri MA. 1998. Ecological impacts of industrial agriculture and the possibilities for truly sustainable farming. *Monthly Review 50*(3): p.60.

Altieri MA. 2004. Linking ecologists and traditional farmers in the search for sustainable agriculture. *Front Ecol Environ* 2:35–42.

Altieri M, Nicholls C. 2004. An Agroecological Basis for Designing Diversified Cropping Systems in the Tropics. *Journal of Crop Improvement* 11: 81-103. 10.1300/J411v11n01_05.

Anon. 2015. shodhganga.inflibnet.ac.in/jspui/bitstream/10603/68588/7/07_experiment.pdf (last accessed 25th December, 2018)

Ardiwinata RO. 1953. Common carp culture in rice fields. *Vorhink Van Hoeve Vol. V. Bandung's Gravenhage* (in Indonesian with English summary).

Bambaradeniya CNB, Amerasinghe FP. 2003. Biodiversity Associated with Rice Field Agroecosystem in Asian Countries: A Brief Review. *International Water Management Institute, Colombo, Sri Lanka. Working paper* 63.

Benton TG, Vickery JA, Wilson JD. 2003. Farmland biodiversity: is habitat heterogeneity the key?. *Trends in Ecology & Evolution 18*(4): pp.182-188.

Brown ME, Funk CC. 2008. Climate. Food security under climate change. *Science* 319: 580–581.

Balzer T, Balzer P, Pon S. 2002. Traditional use and availability of aquatic biodiversity in rice-based ecosystems – I. Kampong Thom Province, Kingdom of Cambodia. *In* Halwart M, Bartley D. ed.

FAO Inland Water Resources and Aquaculture Service. CD ROM, ISBN 92-5-104820-7. FAO, Rome. Available at ftp://ftp.fao.org/fi/CDrom/AwarnessAgrBiodiv/ default.htm.

Banerjee Sachindramohon. 1986. *Jeol Machh*, West Bengal State Book Board.

Bashar KM, Haque MM, Zaman HMS. 2004. Rice biodiversity and genetic wealth of flood-prone environment of Bangladesh. *In* Bhuiyan SI, Abedin MZ, Singh VP, Hardy B ed. *Rice research and development in the flood-prone ecosystem.* Proceedings of the international workshop on flood-prone rice systems held in Gazipur, Bangladesh, 9-11 January 2001. International Rice Research Insitute, Los Baños

Bhuiyan, A L. 1964. *Fishes of Dacca*. Asiatic Society of Pakistan, Dacca.

Bhuiyan, S A, Islam, M N, Hossen T. 1992. *A check list of the fishes of Rajshahi*. The Rajshahi University Studies.

Bhupathy S, Webb RG, Praschag P.2014. *Lissemys punctata* (Bonnaterre 1789)–Indian Flapshell Turtle. Conservation Biology of Freshwater Turtles and Tortoises: A Compilation Project of IUCN/ SSC Tortoise and Freshwater Turtle Specialist Group. *Chelonian Research Monographs* pp.076.1.

Cai R, Ni D, Wang J. 1995. Rice-Fish culture in China: the past, present and future p. 3-14. *In* MacKay KT ed. Rice-fish culture in China. *International Development Research Centre (IDRC)* Ottawa, Canada, 276 p.

Catling, D., 1993. *Rice in deep water*. Springer.

Cheng W, Okamoto Y, Takei M, Tawaraya K, Yasuda H.2015. Combined use of Azolla and loach suppressed weed *Monochoria vaginalis* and increased rice yield without agrochemicals. *Organic Agriculture*, *5*(1): pp.1-10.

Chowdhury M F. 1981. A study on the chemical composition and nutritive quality of some freshwater zeolfishes of Bangladesh. *Faculty of Fisheries, Bangladesh Agricultural University.*

Choulamany X. 2005. Traditional use and availability of aquatic biodiversity in rice-based ecosystems. III. Xieng Khouang and Houa Phanh provinces, Lao PDR. In Halwart M, Bartley D Ed. S. Funge-Smith guest Ed. 2005. *Aquatic biodiversity in rice-based ecosystems. Studies and reports from Cambodia, China, Lao People's Deomcratic Republic and Viet Nam*. [CD-ROM]. Rome, FAO. Also available at ftp://ftp.fao.org/FI/CDrom/AqBiodCD20Jul2005/Start. pdf

Coche AG. 1967. Fish culture in rice fields. A worldwide synthesis. *Hydrobiologia* 30:11-44.

Coomes OT, McGuire S J, Garine E, Caillon S, McKey D, Demeulenaere E, Jarvis D, Aistara G, Barnaud A, Clouvel P, Emperaire L. 2015. Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. *Food Policy 56*: pp.41-50.

Daily G C, Ehrlich P R, Arturo Sanchez-Azofeifa G. 2001. Countryside biogeography: use of human-dominated habitats by the avifaua of sourthern Costa Rica. *Ecological Applications* 11: 1-13.

Demaine H, Halwart M. 2001. An overview of rice- based small-scale aquaculture, p. 189-197. *In* IIRR, IDRC, FAO, NACA and ICLARM. *Utilizing different aquatic resources for livelihoods in Asia: a resource book. International Institute of Rural Reconstruction, International Development Research Centre, Food and Agriculture Organization of the United Nations, Network of Aquaculture Centers in Asia-Pacific, and International Center for Living Aquatic Resources Management* p. 416

Dugan P, Dey M M, Sugunan V V. 2006. Fisheries and water productivity in tropical river basins: enhancing food security and livelihoods by managing water for fish. *Agricultural Water Management* 80: 262–275.

Elvevoll EO, James DG.2000. Potential benefits of fish for maternal, foetal and neonatal nutrition: a review of the literature. *Food, Nutrition and Agriculture* 27: pp.28-39.

FAO. 1957. Fish culture in rice fields p. 193-206. *In* A preliminary review and annotated bibliography from Section II and III of Proc. Indo-Pacif. Fish. Coun. 7. FAO, Rome.

Fedoruk K, Leelapatra W. 1992. Rice field fisheries in Thailand p. 91-104. *In* De la Cruz CR, Lightfoot C, Costa-Pierce BA, Carangaland VR, Bimbao MP. ed. *Rice- fish research and development in Asia.* ICLARM Conf. Proc. 24: p. 457

Fernando C H. 1993. Rice field ecology and fish culture – an overview. *Hydrobiologia* 259:91-113.

Gliessman SR. 1990. Agroecology: researching the ecological basis for sustainable agriculture. In *Agroecology* (pp. 3-10). Springer, New York, NY.

Godfray HCJ, Beddington, JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C. 2010. Food security: the challenge of feeding 9 billion people. *science 327*(5967): pp.812-818.

Gregory R. 1996. Rice field fisheries handbook. Cambodia-IRRI-Australia Project. *Phnom Penh* p. 37

Gregory R, Guttman H. 1996. Capture or culture? *ILEIA Newsl.* 12 (2):p.20-21 Gurung T B, Wagle S K. 2005. Revisiting underlying ecological principles of rice-fish integrated farming for environmental, economical and social benefits. *Our Nature* 3:1–12.

Guo Qing-hua. 1986. Lao Dao Si Han Dynasty Tomb in Mian County, Shaanxi Province. *Agricultural Archaeology*, Vol. I.

Haque .1974. Physiological behavior of deep-water rice, Proceedings of the International Seminar on Deepwater Rice, August 21–26, 1974. No. 15, 1975. Bangladesh Rice Research Institute, Dhaka, pp 184–190

Halwart M. 2003. Recent initiatives on the availability and use of aquatic organisms in rice-based farming, p. 195-206. In *Proceedings of the 20th Session of the International Rice Commission.* Bangkok, Thailand, 23- 26 July 2002. FAO, Rome.

Halwart M, Gupta M V. 2004. Culture of fish in rice fields. Food and Agriculture Organization of the United Nations and the WorldFish Center p. 83

Halwart M, Bartley D. 2007. Aquatic biodiversity in rice-based ecosystems pp. 181-199. *In* Jarvis DI, Padoch C, Cooper HD. ed. *Managing biodiversity in agricultural ecosystems*. Columbia University Press. p. 492

Halwart M. 2008. Biodiversity, nutrition and livelihoods in aquatic rice-based ecosystems. *Biodiversity 9*(1-2): pp.36-40.

Heckman CW. 1979. Rice field ecology in Northeastern Thailand. *Monographs Biologicae* 34:1-228. Dr. W. Junk Publishers, The Hague.

Heckman CW. 2005.Evolution from marsh to rice field. *In* Fernando CH, Goeltenboth F, Margraf J. ed. *Aquatic ecology of rice fields – a global perspective.* Volumes Publishing, Kitchener, Ontario, Canada, pp. 429

Hu L, Zhang J, Ren W, Guo L, Cheng Y, Li J, Li K, Zhu Z, Zhang J, Luo S, Cheng L. 2016. Can the co-cultivation of rice and fish help sustain rice production?. *Scientific reports 6*:p.28728.

Khumairoh U, Lantinga EA, Schulte RP, Suprayogo D, Groot JC. 2018. Complex rice systems to improve rice yield and yield stability in the face of variable weather conditions. *Scientific reports 8*(1):p.14746.

Khush G. 1997.Origin, dispersal, cultivation and variation of rice. *Plant Mol Biol* 35:25–34

Koesoemadinata S, Costa-Pierce BA. 1992. Development of rice-fish farming in Indonesia: past, present and future, p. 45-62. *In* De la Cruz CR, Lightfoot C, Costa-Pierce BA, Carangal VR, Bimbao MP. ed. *Rice-fish research and development in Asia.* ICLARM Conf. Proc. 24: p. 457

Kuronoma, K. 1980. Carp culture in Japanese rice fields. (Edited and condensed by R.S.V. Pullin from the author's original work published in 1954), p. 167-174. *In* Pullin RSV, Shehadeh ZH .ed. 1980. Proc. of the ICLARM-SEARCA Conf. on Integrated Agriculture- Aquaculture Farming Systems, Manila, Philippines, 6-9 August 1979: 258 p.

Li K. 1988. Rice-fish culture in Asia: a review. *Aquaculture* 71:173–186.

Li, K. 1992. Rice-fish farming in China: past, present and future, p. 17-26. *In* de la Cruz CR, Lightfoot C, Costa-Pierce BA, CarangalVR , Bimbao MP. ed. Rice- fish research and development in Asia. ICLARM Conf. Proc. 24: p. 457

Little D C, Surintaraseree P, Taylor N I. 1996. Fish culture in rain fed rice fields of northeast Thailand. *Aquaculture* 140: 295–321

Luo, A. 2005. Traditional use and availability of aquatic biodiversity in rice-based ecosystems. II. Xishuangbanna, Yunnan province, P.R. China. *In* Halwart M, Bartley D. ed. Margraf J. guest ed. 2005. *Aquatic biodiversity in rice-based ecosystems. Studies and reports from Cambodia, China, Lao People's Deomcratic Republic and Viet Nam*. [CD-ROM]. Rome, FAO. Also available at ftp://ftp.fao.org/FI/ CDrom/AqBiodCD20Jul2005/Start.pdf

MacDonald GM. 2010. Water, climate change, and sustainability in the southwest. *Proceedings of the National Academy of Sciences*, *107*(50): pp.21256-21262.

Mackill DJ, Khush GS. 2018. IR64: a high-quality and high-yielding mega variety. *Rice*, *11*(1): p.18

MacKay KT. 1992. Why do rice-fish research on farms? p. 393-397. *In* De la Cruz CR, Lightfoot C, Costa- Pierce BA, Carangal VR, Bimbao MP. ed. *Rice-fish research and development in Asia*. ICLARM Conf. Proc. 24: p. 457

Matteson P C. 2000. Insect-pest management in tropical Asian irrigated rice fields. *Annual Review Entomology*, 5: 549–574.

Meusch E. 2005.Traditional use and availability of aquatic biodiversity in rice-based ecosystems. IV. Lai Chau and Hoa Binh provinces, Viet Nam. *In* Halwart M, Bartley D. ed. 2005. *Aquatic biodiversity in rice-based ecosystems. Studies and reports from Cambodia, China, Lao People's Deomcratic Republic and Viet Nam*. [CD-ROM]. Rome, FAO. Also available at ftp://ftp.fao.org/FI/CDrom/AqBiodCD20Jul2005/ Start.pdf

Pain DJ, Pienkowski MW. 1997. Farming and birds in Europe: the Common Agricultural Policy and its implications for bird conservation. *Academic Press.*

Pautasso M, Aistara G, Barnaud A, Caillon S, Clouvel P, Coomes OT, Delêtre M, Demeulenaere E, De Santis P, Döring T, Eloy L. 2013. Seed exchange networks for agrobiodiversity conservation. A review. *Agronomy for sustainable development 33*(1): 151-175.

Perez AT, Nasiruddin M. 1974. Field notes on the Rayadas: a flood-tolerant deepwater rice of Bangladesh *In Proceedings of the International Seminar on Deepwater Rice,* vol 15, August 21–26, 1974. Bangladesh Rice Research Institute, 1975, Dhaka, pp 87–91

Piao S, Ciais P, Huang Y, Shen Z, Peng S, Li J, Zhou L, Liu H, Ma Y, Ding Y, Friedlingstein P, 2010. The impacts of climate change on water resources and agriculture in China. *Nature 467*(7311): p.43.

Pingali PL, Roger PA. ed. 2012. Impact of pesticides on farmer health and the rice environment (Vol. 7). *Springer* Science & Business Media.

Robinson S, Thomas SM, Toulmin C. 2010. Food security: the challenge of feeding 9 billion people. *science 327*(5967): 812-818.

RogerPA.1996.Biology and management of the floodwater ecosystem in rice fields. *International Rice Research Institute*, Los Banos, Laguna, Philippines, p. 250

Roos N, Leth T, Jakobsen J, Thilsted SH . 2002. High vitamin A content in some small indigenous fish species in Bangladesh: perspectives for food-based strategies to reduce vitamin A deficiency. *Int. J. Food Sci. Nutr.* 53: 425-437

Schilling C. 2004. Resource degradation and food security in Cambodia. A baseline study on the impact of the degradation of the natural fish resources upon food security and nutrition on rural households in Kampong Thom/Cambodia. Scientific thesis in human geography, Department of Human Geography, Albert-Ludwigs-University, Freiburg, F.R. Germany (unpublished).

Smith JD. ed. 2001.Biodiversity, the life of Cambodia – Cambodian Biodiversit Status Report. Cambodia Biodiversity Enabling Activity. Phnom Penh, Cambodia.

Simpson IC, Roger PA, Oficial R, Grant IF. 1994. Effects of nitrogen fertilizer and pesticide management on floodwater ecology in a wetland ricefield. *Biology and fertility of soils*, *17*(2): 129-137.

Söderström BO, Kiema S , Reid R. 2003. Intensified agricultural land-use and bird conservation in Burkina Faso. *Agriculture Ecosystems & Environment*. 99: 113-124.

Talwar PK, Jhingran AG. 1991. Inland Fishes of India and adjacent countries. Oxford-IBH Publishing Co. Pvt. Ltd.,, N. Delhi, Mumbai, Kolkata.

Tamura. 1961. Carp cultivation in Japan, p. 103-120. *In* Borgstrom G. ed. Fish as Food. Vol. 1. Academic Press, New York.

Tsuruta T, Yamaguchi M, Abe SI, Iguchi KI. 2011. Effect of fish in rice-fish culture on the rice yield. *Fisheries Science*, *77*(1): 95-106.

Vincke MMJ. 1995. The present state of development in continental aquaculture in Africa, p. 27-61. *In* Symoens JJ, Micha J-C. ed. Proceedings of the Seminar on "*The Management of Integrated Agro- Piscicultural Ecosystems in Tropical Areas*", 16-19 May 1994. Tech. Center for Agric. and Rural Co-op. (CTA) Royal Academy of Overseas Sciences, Brussels, 587 p.

Spiller G. 1985. Rice-cum-fish production in Asia: Aspects of rice and fish production

Wang J, D Ni. 1995. A comparative study of the ability of fish to catch mosquito larva, p. 217-222. *In* MacKay KT. ed. 1995. Rice-fish culture in China. International Development Research Centre (IDRC) Ottawa, Canada, 276 p.

Wittman H, Desmarais A, Wiebe N. 2010. The origins and potential of food sovereignty. *Food sovereignty: Reconnecting food, nature and community*, pp.1-14.

Xie J, Hu L, Tang J, Wu X, Li N, Yuan Y, Yang H, Zhang J, Luo S, Chen X.2011. Ecological mechanisms underlying the sustainability of the agricultural heritage rice–fish coculture system. *Proceedings of the National Academy of Sciences*, *108*(50):E1381-E1387.

Zheng H, Huang H, Li D, Li X, Fu Z, Chen C. 2014. Assessment of nomadic rice-duck complex ecosystem on energy and economy. *Ecological Processes*, *3*(1):p.20.

Zhu Y, Chen H, Fan J, Wang Y, Li Y, Chen J, Fan J, Yang S, Hu L, Leung H, Mew TW. 2000. Genetic diversity and disease control in rice. *Nature 406*(6797): p.718

Yin Pi-zhen. 1983. Talks about rice field fish culture from the point of view of science and technology. In: Proceedings of the First National Rice Field Fish Culture Seminar, 11-15 August 1983 at Wenjiang, Sichuan Province, China, pp. 167-178.

Annexure 1: Rice Varieties Suited to Different water Depth and Soil Salinity

Name of the Varieties	Water Depth	Soil Salinity (mmhos/cm)
HORMANONA, MEGI	200 cm	<2
KUMARGORE, TALMUGUR	60 cm	<2
HAMILTON, MATLA, NONABOKRA, NONASAIL	25 cm	5-8
KALOMOTA, KAGGABATH	50 cm	5-8

Annexure 2: List of Govt. Institutions / NGOs where Flood Tolerant and Salinity Tolerant Indigenous Paddy Varieties are Conserved.

1. Agricultural Training Centre. Fulia, Nadia,.
2. Richharia Conservation Centre, Pratappur, Aushgram, Burdwan and Center for studies in Ethnobiology, Biodiversity, and Sustainability (CEiBa), Malda, West Bengal
3. Brihi, Panchal, Bankura.