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ICAR

Research
Bulletin
42

Rice-fish Culture : An Ingenious Agricultural Heritage System

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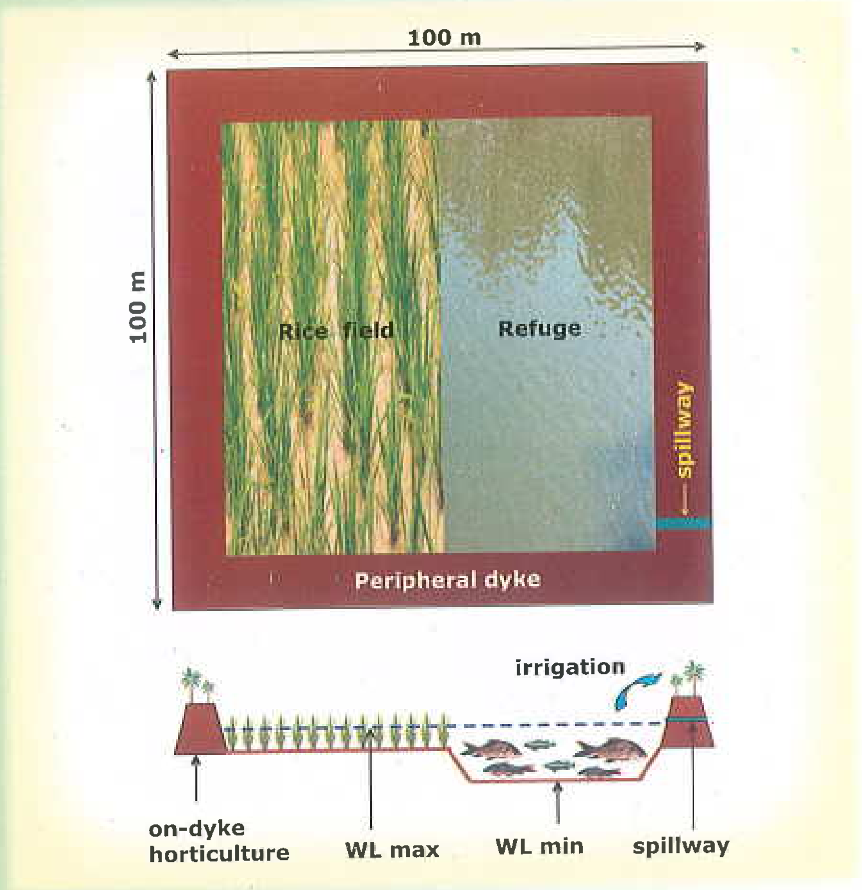

WATER TECHNOLOGY CENTRE FOR EASTERN REGION
(Indian Council of Agricultural Research)
Chandrasekharpur, Bhubaneswar - 751 023, Orissa, India
2008

WTCER

Research Bulletin
Publication No. 42

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An Ingenious Agricultural Heritage System

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Correct citation:

Mohanty, Rajeeb K., Jena, S.K., Ashwani Kumar, Sahoo, N. and Roy Chowdhury, S., 2008. Rice-fish Culture: An Ingenious Agricultural Heritage System. *Research Bulletin No.-42.* Water Technology Centre for Eastern Region, Indian Council of Agricultural Research, Chandrasekharpur, Bhubaneswar, India, 54 p.

Published by:
Director,
Water Technology Centre for Eastern Region,
(Indian Council of Agricultural Research)
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Printed by:
Capital Business Service & Consultancy
B-51, Sahid Nagar, Bhubaneswar-751007

Preface

Presently, we live in a world where poverty, hunger and malnutrition are prevalent. It has been estimated that 14% of global population or 855 million people are going hungry and of those 690 million are in the Asia-Pacific region. 50% of the hungry are in smallholders farming households and 30% among the landless poor. These statistics reveal the unpalatable truth that in a world, which has both resources and knowledge, the situation remains a continuing travesty of the recognized fundamental human right to adequate food and freedom from hunger and malnutrition. Keeping these in view, the Millennium Development Goals adopted by the world's governments in the year 2000, set a target of halving the hungry and malnourished population by 2015. However, to meet the target with limited land and water resources available with us, integrated aquaculture-agriculture (IAA) seems to be a viable option in enhancing food production and water productivity. Fish are a rich source of protein, highly beneficial essential fatty acids, vitamins and minerals, which are difficult to obtain from other food sources, can easily be integrated with rice, the most preferred crop in India and South Asia. The integration of rice and fish culture promises ecologically sound and economically successful management of waterlogged/ lowland ecosystem. This eco-friendly and easily replicable system encourages synergism between components and recycles the wastes of one another leading to higher yield and productivity. Rice-fish farming systems, as part of an integrated ecosystem in line with the local cultural, environmental and economic conditions, are composed of complementary sub-agricultural ecosystems and play important ecological service roles, such as bio-control, nitrogen fixation and landscape combination.

In this backdrop, WTCER (ICAR), Bhubaneswar had initiated an on-farm research on 'Deepwater high-density rice-fish culture' based on the principle of high initial stocking followed by phased harvesting. The selected study site was one of the lowest productive areas of Orissa state, prone to chronic water logging problem. In this agricultural production system, traditional agriculture has been intensified by inclusion of diverse horticultural crop in integration with pisciculture, which could be a practical example for development of economically viable integrated agri-aquacultural production system in waterlogged area. We sincerely hope that our effort in bringing out this research bulletin based on on-farm field trial will be helpful for all those engaged in deep water rice-fish culture and its management. This will also serve as a source of information to farmers, policy makers, entrepreneurs, researchers and extension workers as training guide.

15th August, 2008

AUTHORS

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1.0 INTRODUCTION

Rice-fish farming system constitute a unique agro-landscape across the world, especially in tropical and sub-tropical Asia (Haroon and Pittman, 1997) and is no longer a sole agro-production practice, but an agro-cultural pattern. Keeping in view, the outstanding contribution of rice-fish farming to food and livelihood security, its importance in terms of biological diversity and genetic resources, landscape diversity, aesthetic beauty, cultural values, other ecosystem goods and services and indigenous knowledge of land and water management, it has been listed by FAO and UNESCO as one of the Globally Important Ingenious Agricultural Heritage System (GIAHS). Rice, the dominant staple crop of tropical Asia with a long history of domestication, and has a rich diversity of cultivated ecotypes based on three varieties of *Oryza sativa*: *indica, japonica* and *javanica*. There are four basic rice agro-ecosystems each with particular edaphic conditions: irrigated ecosystem, upland and lowland rainfed ecosystem and flood prone (deep water) ecosystem. Fish rearing in rice fields is a 2000-year-old apparently successful practice, where fish are stocked with the aim of increasing and diversifying the rice field productivity and is probably the most promising alternative to rice mono cropping. Fish culture in this ecosystem is concurrent or rotational with rice carried out at four intensities: traditional (capture), low intensity culture (without feed and fertilizer), medium intensity (only fertilization) and high-density culture (with feed and fertilizer). The integration of fish into rice farming provides invaluable protein, especially for subsistence farmers who manage rain-fed agricultural systems. Rice fields provide shade and organic matter for fish, which in turn oxygenate soil and water, eat rice pests and favor nutrient recycling. In most countries, rice-fish farming is characterized by intensive rice-culture and extensive fish-culture, where fish yields are usually very low, about 300 kg ha^{-1} (Nhản et al., 1998). Rice-fish farming systems, as part of an integrated ecosystem in line with the local cultural, environmental and economic conditions, are composed of complementary sub-agricultural ecosystems and play important ecological service roles (Fernando,1993), such as bio-control, nitrogen fixation and landscape combination.

In India, agriculture, the lifeline of Indian economy, contributes nearly one-fourth of the national GDP and sustains livelihood of about two-thirds of population. It is projected that to meet the food requirement of 1.5 billion people by 2050, the food grain production has to increase by 185% which infact possible through enhancement of productivity, crop diversification and cropping intensity. However, presently, there is little scope for horizontal expansion of agriculture/aquaculture due to rapid industrialization and urbanization. India's per capita availability of land has also dropped from 0.5 ha to 0.15 ha. Further, India's population has crossed 1060 million including undernourished population of 270 million. Under this scenario, meeting the food requirements of the burgeoning population has turned out to be a challenging task. Vertical expansion by integrating compatible farming components requiring lesser space and time, and ensuring periodic income to farmer therefore, seems to be a viable alternative which assume greater importance for sound management of farm resources. This would definitely enhance farm productivity, reduce environmental degradation, improve quality of life of the resource poor farmers and maintain the sustainability. On other hand, the most serious constraint in aquaculture technology is the high cost of inputs, especially fish feed and fertilizer. Further, stocking of healthy fingerlings of more than 100 mm is an essential management measure, to enhance fish production. However, inadequate land-based nursery ponds available at present and financial constraints in developing new infrastructure facilities impede the desired stocking programme. With these constraints and available resources, rice field ecosystem, provide a viable opportunity for mass scale fry to advanced fingerling rearing, as a part of stocking programme.

Further, out of 44.5 million hectare of rice cultivated land in India, 20 million ha is suitable for adoption of rice-fish integration system mainly in rainfed medium lands, waterlogged / low lands and in canal commands. However, only 0.23 million ha is presently under rice-fish culture. This low degree of adoption, exploitation and yield is primarily due to introduction of high-yielding rice varieties involving the use of pesticide etc. that has greatly impeded fish culture in paddy fields, shorter rearing duration for fish, insufficient water availability, lack of water management measures and erratic monsoon. Achieving a higher productivity from these under utilized high potential area is thus an immediate need, particularly in the eastern region. If these lands were brought under integrated rice-fish system with suitable scientific intervention and water conservation / monitoring measures, it would help to compensate the economic losses in rice production brought about by natural calamities. Rice-fish culture could be a viable option for diversification for smallholder rice farmers in low lands with soil and water conservation structures and reliable source of water for irrigation (Ofori et al.,2005). Integrated rice-fish farming not only accommodates crop diversification, enhance productivity, generate employment opportunity, increase income and provide nutritional security to resource poor farming community but also distribute the risk (both biological and economic), since two or more subsystems are involved instead of a single-commodity farming system. Rice-fish integration is therefore, a primary option when trying to develop ecological agriculture that exploit maximum benefit from the system, avoid harmful effects and strive for maximum out put using available energy and materials. Further, Adding fish to the rice field ecology helps increase production and achieves social, economic and ecological benefits (Costa-Pierce,1992; Xiao,1995; Halwart et.al.,1996; Rothuis et.al.,1998 and Bandyopadhyay and Puste,2001).

1.1 Global and Indian Scenario

Rice-Fish Integration: Global Scenario

Rice-fish farming systems have a long history in China (Khoo and Tan,1980; Zhang,1995 and Halwart,1998) and has been practiced in 28 countries on six continents: Africa, Asia, Australia, Europe, North America and South America (Suloma and Ogata, 2006). In

Japan, the practice began only in the last century and in Java, in the mid-nineteenth century. Rice-fish farming has followed a chequered pattern in Thailand since its introduction by the Department of Fisheries (DOF) in central and eastern Thailand in the 1950s (Little et al., 1996). In Africa, the introduction of an Asian-based Sawah farming system through an eco-technology approach has opened a new frontier for diversification of the rice-based cropping system, and on-farm rice-fish-culture experiments have been reported in recent year (Ofori et al., 2005). The reported highest fish yield from rice-fish system is so far 7.03 t ha^{-1} (Chen et al., 1995) while, 3.6 t ha^{-1} in India (Brahmanand *et al.*, 2006), 2.5 t ha^{-1} in China, 2.2 t ha^{-1} in Vietnam, 0.98 t ha^{-1} in Bangladesh, and 0. 9 t ha^{-1} in Thailand and 0.8 t ha^{-1} in Indonesia (Haroon and Pittman, 1997). Significant work on rice-fish farming has also been done in other countries such as Philippines (Sevilleja,1992), Indonesia (Koesoemadinata and Costa-Pierce,1992), Bangladesh (Gupta et.al.,1998; Oheme et.al.,2007 and Frei et.al.,2007a), Vietnam (Cagauan et.al.,2000), Thailand, Malaysia (Ali,1990), Korea (Kim et.al.,1992) etc. Generally three types of field designs for rice-fish farming predominate i.e. shallow trench within the rice-field (in Philippines, Indonesia and China), pond refuge adjacent to the rice field (in Indonesia, India, Thailand and China) and deep water rice fields (Bangladesh). Concurrent culture of fish and rice as well as rotational systems where fish are grown after rice are common throughout Asia. Country analysis shows that rice-fish systems presently occupy only a very small percentage of the potential area. The wide array of systems that exist can be broadly characterized by field design, growing period and fish species. Two types of growing period, concurrent with the rice and rotational after the rice, are found. Carp, tilapia, silver barb, snakeskin gourami and prawns are usually grown. Researches on productions systems revealed that while most systems are for grow out operations; rice fields are also suitable for nursery operations.

Combinations of rotational and concurrent rice-fish systems arranged in one year sequential cropping pattern are best developed in Indonesia. When practices in combination, these systems can produce annual fish yield over 900kg/ha. Rice fields are being used both as fish nursery and grow out for table fish in Indonesia, China and in Thailand. Interestingly, raising fingerlings in rice fields was more profitable than grow out. Published data on rice yields from China, India, Indonesia, Philippines and Thailand reveals that average percentage increases in rice yields ranged from 4.6 to 28.6% while in India, it is between 9 and 23%. Among the countries listed, Indonesia is second to China in rice area being used for rice-fish farming. Fish culture is concentrated in irrigated and coastal rice lands. Although it is much smaller in area, Thailand is next to Indonesia in the extent of rice-fish culture. Fish are grown in many different ways in both irrigated and rainfed environments. Bangladesh has more than 2 million ha of deep-water rice areas. The potential of this resource for stocking and feeding fish has not been tapped yet. The area devoted to rice-fish farming in the Philippines is still limited. Rice-fish culture techniques for irrigated rice using tilapia and carp have not yet diffused to many farmers.

The most important fish species found in rice field systems are carps (Indonesia, India, China), tilapias (Philippines, China, Thailand), *Puntius gonionotus* (Thailand), and *Trichogaster pectoralis* (Thailand). In general, the main species that are stocked in rice fields are *Cyprinus carpio* and *Oreochromis niloticus.* However, *Barbodes gonionotus* (Bleeker) is often stocked in poly-culture (with Indian major carps) in rice fields in India and Bangladesh and with local varieties mainly olfactory feeders, in southeast Asia (Vormant et al., 2002; Little et al., 1996; Mohanty et al, 2004, Ofori et al., 2005). Both mono and poly culture of these species are practiced. Many other species of fish and other animal (e.g. shrimps and frogs) are found in rice fields. In deep water and coastal areas of Bangladesh, India and Vietnam, shrimps/freshwater prawn (*Macrobrachim rosenbergii*) and finfishes are stocked during wet or monsoon months; while marine shrimps and fishes are culture during summer or saline water months. Thailand, Bangladesh and India have seasonally important rice field capture fisheries system. Furthermore, Indonesian farmers integrate ducks and home gardens into their rice-fish culture systems. Increasingly, fish is viewed as a tool within an integrated pest management (IPM) system to make rice production more sustainable and environment friendly, as well as having direct monetary benefits and/or nutritional value, such as in Thailand, Vietnam and Bangladesh (Berg, 2001; Haroon and Pittman, 1997; Little et al., 1996). According to Berg's report (2001), during the 3 years of IPM in Vietnam, farmers on rice-fish farms estimated that they had decreased the amount of pesticides used by approximately 65%, whereas non-IPM framers had increased the amount of pesticide used by 40%.

Global Experiences

China has the oldest archaeological and documentary evidence for rice-fish farming. In 1954 it was proposed that development of rice-fish culture should be spread across the country (Cai et al 1995) and by 1959, the rice-fish culture area had expanded to 666 000 ha. From the early 1960s to the mid 1970s there was a temporary decline in rice-fish farming. This was attributed to two developments: first, the intensification of rice production and second the ten-year Cultural Revolution (1965-75). By 1996, China had 1.2 million ha of rice-fish farms producing 377 000 t of fish (Halwart 1999). Rice-fish farming appears to be of minor importance in Japan and there is not much literature on the subject. After reaching a peak production of 3 400 t in 1943 due to war-time food production subsidies, carp production in rice fields decreased to 1 000 t during the 1950s and it is no longer practiced on a significant scale, if at all. In Korea, rice-fish farming started only in the 1950s and never spread widely because the fish supply from inland waters was sufficient to meet the limited demand for freshwater fish. As of 1989 only 95 ha of rice fields were being used for fish culture, and only for the growing the most popular species of loach (*Misgurnus anguillicaudatus*).

Rice-fish farming is believed to have been practiced in Indonesia, even before 1860 although its popularization apparently started only in the 1870s. By the 1950s some 50 000 ha of rice land were already producing fish. The development of irrigation systems also contributed to the expansion of the area used for rice-fish farming. The average area of rice-fish farming increased steadily after Indonesia became independent in 1947 and rice-fish farms covered 72 650 ha in 1974, but declined to less than 49 000 in 1977. The decline was attributed, ironically, to the government's rice intensification program. Recent reports indicate that rice-fish farming is on the upswing. The 1995 figures from the Directorate General of Fisheries indicate a total area over 138 000 ha. At present rice-fish farming is practiced in 17 out of 27 provinces in Indonesia.

Integrated rice-fish farming is believed to have been practiced for more than 200 years in Thailand, particularly in the Northeast where it was dependent upon capturing wild fish for stocking the rice fields. It was later promoted by the Department of Fisheries (DOF) and expanded into the Central Plains. The provision of seed fish and technology helped in popularizing the concept. However, during the 1970s, Thailand, like the rest of Asia, introduced the HYVs of rice and with it the increased use of chemical pesticides. This resulted in the near collapse of rice-fish farming in the Central Plains as farmers either separated their rice and fish operations or stopped growing fish altogether. However, rice-fish farming has recovered, particularly in the Central Plains, North and Northeast Regions. Presently, more than 25 500 ha is under rice-fish farming. In Malaysia, the practice of rice-fish farming appeared as early as 1928 and the rice fields have always been an important source of freshwater fish. Fish production from rice field started to decline with the introduction of the double-cropping system and with it the widespread use of pesticides and herbicides (Ali 1990). Vietnam has a strong tradition of integrating aquaculture with agriculture. Le (1999) reports five common rice-fish culture systems being practiced in Vietnam. These five systems are fish-cum-rice for nursery and growout, fish-cum-rice for grow out only, shrimp-cum-rice, fish/rice rotation and shrimp/rice rotation.

In the Philippines, fish are traditionally allowed to enter the rice fields with the irrigation water and are later harvested with the rice. In spite of the lower rice yields, in 1979 the government proceeded to promote rice-fish farming nationwide. The decision was based on the results of the economic analysis that even with a reduced rice production, the farmer would still be economically ahead due to the additional income from the fish. After a peak of 1 397 ha involving 2 284 farms in 1982, the program was discontinued in 1986. At that time the average production of rice from rice-fish farms was above the national average. However, it was re-lunched during 1999 with a more modest rice-fish program in the Philippines. Farmers in Bangladesh have been harvesting fish from their rice fields for a very long time. Bangladesh is one of the few countries actively promoting rice-fish farming and pursuing a vigorous research and development program. NGOs in Bangladesh are likewise showing increasing interest in rice-fish farming. More recently, CARE has become the most active NGO involved in rice-fish farming. The traditional *bheri* system is used wherein the rice fields are enclosed by small embankments complete with inlet channels and sluice gates. Fields vary in sizes from 3 to 50 ha. Both rotational and concurrent systems are practiced. Thousand of farmers in Bangladesh have experimented with rice-fish culture and have developed practices to suit their own farming systems. Initially the adoption rate was lower among females, but the activity is reported to be gaining popularity among both male and female groups.

In Africa, the earliest report on rice-fish culture comes from Madagascar as early as 1928. Both concurrent and rotational systems relying on entry of natural fish stock were practiced. Only in 1979, sufficient progress was made for the government to promote rice-fish culture. However, an average yield of 80 kg.ha^{-1} indicates that culture techniques at the farm level still need to be improved (Randriamiarana et al 1995). A country with almost 900 000 ha of rice fields does have a great potential for rice-fish farming as about 150 000 ha cold be suitable for rice-fish farming. A potential annual production of 300 000 t of edible fish has been projected from the said areas. Farmers in Malawi are just beginning to grow rice and fish together as well as fish and vegetables. Although not specifically mentioned, the fish involved are apparently tilapia, the principal species in the country. Egypt, which is the biggest rice producer in Middle East, started with a capture-type of rice-fish farming based totally on occasional fish stock coming in with the irrigation water. The rice-fish farming area expanded considerably using reclaimed salt-affected lands and in 1989 reached a peak of 225 000ha and again declined to 172 800 ha by 1995. By 1995 fish production from rice fields accounted for 32% of the total aquaculture production in the country. Since then 58 000 ha of farmland have been added producing 7 000 t of *C.carpio* in 1997 (Wassef 2000).

Iran begun rice-fish culture trails in 1997. Chinese major carps are used concurrently with rice, sometimes with supplementary feeding. Productions over 1.5 t of fish per ha together with 7 t of rice have been achieved with a high survival rate (96%), despite an average water temperature of only 23^{0}C during the culture period. In addition, 70 farms have adopted a rotational rice-fish farming system where the rice field is stocked with trout during the winter months when the average water temperature is 12^{0}C, yielding 640 kg.ha^{-1}. Concurrent culture of *M. rosenbergii* with rice is also being tried.

Rice-fish culture was introduced to Italy at the end of the 19th century and was progressively become important during the subsequent 40 years. The main species were *C.carpio, C.auratus* and *Tinca tinca*. The rice fields were used to produce fingerlings that had a ready market. The practice gradually declined and by 1967 it was no longer considered an important activity. Although rice is produced in nine countries in South America and eight countries in the Caribbean, the culture of fish in rice fields is not widespread. Experiments on integrating fish culture with rice production are or were being conducted in Brazil, Haiti, Panama and Peru, but only Brazil appears to have had some degree of commercial success. In the northeast, farmers became interested in semi-intensive rice-fish culture using native fish species. Experiments on intensive rice-fish culture were also conducted in the Paraiba basin using the *C.carpio* and Congo tilapia (*T.rendalli*). The outlook for rice-fish culture is though to be favorable for the region because of its suitable climate and irrigated areas. Rice-fish farming used to be considered important in the United States. However, instead of finfish, crawfish are now being rotated with rice. Two crawfish species are popular because of their hardiness and adaptability, the red swamp crawfish (*Procambarus clarkii*) and to a certain extent the white river crawfish (*P. zonangulus*). The life-cycle of crawfish and environmental requirements lend very well to being rotated with rice. Most of the crawfish produced in the US now come from the rice fields of the southern states.

Rice-Fish Integration: Indian Scenario

Though the practice of rice-fish farming differ from country to country, they all follow the same principle of utilizing or recycling farm resources for production. The major differences in these farming systems are mainly the variations in field design, species composition, stocking density, sizes, crops, crop rotation etc. Usually three types of field designs which included the shallow trench system within the rice field as seen in Philippines, Indonesia and China; pond refuge adjacent to rice field at one side and deep water rice field system are practiced in India. In these systems, different types of land modifications are done for keeping and rearing the fish. In Eastern Indian states, mainly pond refuge and trench system of rice-fish farming is followed whereas broad bed-farrow system is popular in the Andamans. The other traditional modified methods suiting to the source of water and land condition are discussed as following.

Filtration system

This system of rice-fish farming is practiced in the coastal rice field. Seeds of brackish water fishes enter during the saline water ingress to the rice field at high tide through an inlet. The seeds are filtered in to the rice plots by using bamboo mat or net materials. The fishes are allowed to grow in this system for certain period ranging 4-5 months. The system is further protected from entry of predatory fishes in the next high tide by using the velon screen or bamboo mat. Sometimes supplementary feed is given for higher and quicker fattening of the stocked fished. This type of farming is common in the *Pokkalli* fields of Kerala, *Gajani* rice fields of Karnataka, *Khajan* area of Goa and also in West Bengal as the *bhasabada* farming.

Flow though system

In northeastern India, many rice fields are located in valleys where water accumulates from the adjoining hills and flows down the valley by gravity. Dwarf varieties of rice are generally cultivated in such plots integrated mainly with *Cyprinus carpio*. Fish production from such plots range from 200 to 1,000 kg/ha during the monsoon. Recently, such integrated farming is gaining popularity in these areas. Flow-through rice-fish farming system is also practiced in the rice field of hilly terrain by diverting the stream water to the rice fields. Since the rice fields are arranged in steps in these areas, the system of practice is almost similar to that of the running water aquaculture.

Lowland system

In India, waterlogged lowland constitutes the most important potential area for rice-fish farming. The rice-fish farming is generally practiced in the medium to lowland rice fields where at least 30 cm water accumulates and stagnates for more than 4-6 months. Generally two types of fish farming system is practiced in the rice field. It may be the capture-based system or culture system. In capture system, the bunded lowlands or modified rice fields harbours a wide variety of fish fauna such as murrels, catfishes, feather backs, a variety of weed fishes, post larvae of prawns and even the fry and fingerlings of major and minor carps, if the areas is connected to the catchment area of river, canal or streams. The ecosystem provides an excellent breeding ground for catfish and weed fish, which enter into the system during overflow. Since most of these fishes are prolific breeders, a good population is auto-stocked leading to a considerable catch after 3-4 months. In this system, farmers do little or no management during retaining fish. After the rice harvest, the fishes are harvested immediately or left for further growth depending on the water availability. The production in this system is low depending on the auto-stocking and duration of culture. The culture system is practiced in lowland rice growing areas with construction of pond refuge and trenches. The fish farming practices in this system is almost similar to the conventional methods barring restricted use of chemicals and pesticides required for rice crops.

Research and developments

Table 1 presents the summary of the rice-fish farming under natural and research environment in the country. In the natural system rice-fish farming has been carried out in brackish water, rainfed and waterlogged situation. In this system, the yield of fish/ prawn varied between 186 to 2135 kg/ha. Similarly, the rice yield varied between 0.5 to 3 t/ha. In brackish water and low saline water, prawn culture was preferred. The traditional system of shrimp filtration in rice plots of Kerala and Goa has been modified into the current practices. Major changes in the management include the desalinization in *Pokhali* plots through various devices, namely field trenching in a crisscross manner for quick removal of runoff water carrying surface salt deposits that have accumulated during brackish water prawn culture. The aquaculture production from such rice-fish plots has been raised to 785-2135 kg/ha/year. By selective stocking of prawns 80% of the total Basirhat, Malancha, Gopalpur, Haroa, Sandeshkhali and Nzat could be modified to increase fish and prawn production to 600-1000 kg/ha/year. Juvenile mortality has been reduced considerably by recent introduction of the build in nursery system and supplementary feeding. In such a modified method of culture, entry of predator species

Table 1. Rice-fish farming (India experience)

Location	Type of rice plot	Fish stocked	Fish (kg/ha) production	Rice (t/ha) production
Natural System				
East Godavari (wild crop	Deep water (river basin)	Natural stocks	3 / year	1.0-1.5
Kerala (modified *Pokhali* system)	Shallow (brackish water)	*P.monodon*, *P. indicus* and natural stocks	785-2135 / year	1.5-2.5
NE Hill complex (mountain valley)	Waterlogged	*C.carpio*	Highly variable	1.0-1.5
Meghalaya (terrace system)	Shallow (hilly)	*C. carpio*	186 /2 months	0.5-0.8
West Bengal (modified bhasa-badha system)	Shallow (two aquatic crops	*P. monodon*, *L. parsia* and Natural stocks	600-1000 / year	2.5-3.0
West Bengal (ordinary plot)	Rainfed (inland)	Tilapia, murrel, catfish, prawns etc.	300 / year	2.0-3.0
West Bengal (sewage enriched)	Shallow (low salinity)	*P. monodon*, *L.parsia*, *Tilapia* and natural fry	1000 / year	1.5-3.0
Trends in research and development				
State fisheries plot, W.B.	Shallow (nursery)	Carp (1,457 nos/ha)	112 / 3-4 months	2.5-3.7
Karnataka plot	Shallow (nursery)	Crap fry to fingerlings	153 /71 days	1.5-2.0
CSSRI, W.B (SR 26B)	Shallow (brackish water)	Carp & *M. rosenbergii* in Monsoon, *P.mononodon* and *L. parsia* in summer	870 / year	3.0
24 Parganas, WB (Developing)	Shallow (fresh water)	Carp with *M.rosenbergii*	630-930 / year	5.2
24 Parganas, WB (Developing)	Shallow (coastal)	Brackish water shrimp and fish with Tilapia	862 / year	2.7
WTCER (ICAR) Bhubaneswar (2001)	Rainfed medium land	Fry of Indian Major Carp with *M. rosenbergii* (No pesticide used)	1156 / 120 days	3.6
WTCER (ICAR) Bhubaneswar(2004)	Rainfed medium land	Fry of Indian Major Carp and common carp (No pesticide used)	1265 / 180 days	5.3
WTCER (ICAR) Bhubaneswar (2004)	Raised & sunken bed system in canal command	Fingerling of Indian Major Carp	2740 /120 days	3.7
CRRI, Cuttack (2001)	Deepwater lowland	Indian Major Carp & Common Carp	600 /season	4.0
Kuttanad, Kerala (2002)	Polders	*M. rosenbergii*	95-1297 / year	—
WTCER (ICAR) Bhubaneswar (2006)	Deep water high-density rice-fish culture	Fingerlings of Indian Major Carp with *M. rosenbergii*	3480 / 210 days	3.25

is avoided by filtration of incoming water using bamboo mats and nylon nets. In northeastern India, many rice fields are located in valleys where water accumulates from the adjoining hills and flows down the valley by gravity. Dwarf varieties of rice are generally cultivated in such plots integrated mainly with *Cyprinus carpio.* Fish production from such plots ranges from 200 to 1000 kg/ha during the monsoon.

In the derelict polders (embanked coastal flood plains) of Kuttanad, Kerala nearly 55000 ha of wetlands are available for paddy cultivation year-round of which around 5000 ha are utilized for *Macrobrachium rosenbergi* culture as a follow up crop. Out of 5000 ha, about 250 ha fallow polder are utilized for monoculture of *M.rosenbergii* from march to October, while about 4750 ha are utilized for polyculture with Indian and exotic carps from November to June. Stocking density was 15,000 to 60,000 ha for monoculture of *M.rosenbergii*, while in polyculture with carps it was 5,00 to 20,000/ha of prawn and 5000 to 10000/ha of fish. Production from monoculture varied from 95 to 1297 kg/ha, where as production from polyculture systems was 70 to 5000 kg/ha of prawn and 200-1200 kg/ha of fish. Profits ranged from Rs. 500 to Rs. 20000/ha. Utilization of ploders for fish and/or prawn culture is not only helpful in improving the revenue for the farmers but also provides additional employment.

During the last three decades, experiments have been conducted in several states of the country to improve the production potential of fish/prawn in rice fields. Presently most research activities in rice-fish culture are confined to medium lands and deep water rice fields in freshwater and coastal rice fields in brackish water habitats. The State Fisheries Department, Government of West Bengal, undertook nursery rearing of carps in a 279-ha rice field (Hora 1951). Carp fry (19-64 mm) were stocked at 1,457/ha and raised to 127-135 mm size in three to four months. The total yield was estimated to be 112 kg/ha with an overall survival of 34%. Iyenger (1953) carried out some experiments in plots at the Hasserghatta and Visweswarya Farms in Karnataka to control insect pests in the rice fields through stocking of *Channa striata.* The average fish yield in four months was 112 kg/ha, showing a growth of 7-13%. In West Bengal, *H. fossilis* and *C.batrachus* were stocked at 1:2 ratio at 10,000 fingerlings/ha in Randhunipagal rice fields. With no supplementary feeding, catfish yield was 199.4 kg/ha and 1.84 t/ha for rice yields. However, with supplementary feeding (fish meal and rice bran at 1:2 ratio and given 5% of the fish biomass), yields were increased to 375 kg/ha for catfish and 1.88 t/ha for rice. The yield of rice was low (1.79 t/ha) in the control plot without fish. Similarly, *H. fossilis* and *C.batrachus* yields in other rice plots trials were 410 kg/ha (Ratna), 360 (Pankaj) and 490 (Jaya) with rice yields of 3.8, 3.7 and 6.4 t/ha, respectively against 3.2, 3.0 and 5.9 t/ha of rice in the control plots during March-June, July-November, and November-April. Thus in the integrated system, total annual yields were 1,260 kg/ha of offish, 13.4 t/ha of rice and 23.7 t/ha of straw. In these plots, fewer incidences of stem borer were recorded (Dutta et al, 1986).

A 1.09 -ha rice plot in Bandipur, West Bengal, which was producing only one crop of rice (2.7 t/ha/year) in a traditional system, was renovated, keeping 65% of the area in rice, 33% perimeter canal and the rest for dikes. Two crops or rice, Ratna in summer and Jaya in the monsoon, and one annual crop of carp were raised. Yields were 4.2 (Ratna) and 3.2 (Jaya) t/ha of rice and 237 kg/ha/year of carp in the initial phase. In subsequent years, fish yields increased to 630 kg/ha/year. Similarly, in fresh water rice plots with excavation of deeper pools at Minakhan, fish yields ranged from 650 to 930 kg/ha/year and rice yields, 5.1 to 6.4 t/ha/year (Ghosh, 1992). In coastal saline areas of West Bengal, plots belonging to 35 farmers were developed. In recent years, average fish yield in these plots was 826 kg/ha/year and rice yield, 2.7 t/ha during the monsoon season. In low salinity plots near Basirhat in Best Bengal, management practices were further developed and yields improved: 50 kg/ha of P. monodon; 250 kg/ha of mullet; 3,000 kg/ha of tilapia and 2.4 t/ha of rice (Ghosh 1992).

Recently (2001-2006), Water Technology Centre for Eastern Region (ICAR), Bhubaneswar had conducted integrated rice-fish farming in medium lands, lowlands and in modified alternate raised and sunken bed system in four locations of Orissa covering 12 farmers fields. Results indicated that construction of monolateral-type refuge (30-35% of total land area) acts as a drainage system and helps in lowering the water table, can be adopted for rice-fish culture in reclaiming waterlogged area. Ways to intensify fish production from deepwater rice-fish unit can involve management strategies like high-density rearing followed by selective/ cull harvesting, when the growth curve of fish/ prawn starts to slow down. As density-dependent growth performance takes place at higher population density, culling helped in reducing size heterogeneity, weight distribution and stunting growth of fish. Under high-density deepwater rice-fish culture, record yield of rice and fish was achieved @ 3.1 and 3.6 t/ha/crop respectively, where culling enhanced fish & prawn yield by 16.3% and Feed Conversion Ratio by 26% over control. Existence of fish & prawn enhanced rice yield by 22.7%. In this system, fish acts as a bio-controller of insects & aquatic weeds, thus reduces the input cost of insecticide and herbicide by 52-55%. In this system, net economic indices of water productivity (Rs./m^3) increased by 11.3 fold over deepwater rice mono-crop while, farmer can get a net profit of Rs.1,08,500/ha/crop with a B-C ratio of 4.1.

In the rainfed medium land ecosystem, two-stage rainwater conservation (Mohanty et al., 2004 and Mohanty, 2003), short duration rice-fish culture using the excess rainwater harvesting refuge (Mohanty, 2004), integration of on-dyke horticulture and utilization of conserved refuge water for growing low duty *rabi* crops (Mishra & Mohanty, 2004) seem to be a viable solution for increasing the net profit (Rs.39700/ha/crop with a B-C ratio of 2.93) of small and marginal farmers. Addition of poultry/duckery to the system and their droppings in water reduce the input cost of fish feed by 40% and fertilizer cost by 60-65% while B-C ratio goes up to 3.68-3.87. This system is eco-friendly as it promotes synergism between different components leading to recycling of wastes and generates additional farm employment up to 220 man-days/ year. In another experiment of rice-fish co-production using raised and sunken bed system in canal command, fish yield (2740 kg/ 120 days) increased by 29.8% against that of mono-culture system. These developments serve as an impetus for promoting rice-fish farming in India.

1.2 Advantages of integrated rice-fish farming system

In general, stocking of fish in the rice field enhance the soil fertility mainly in three ways: (1) additional nutrients from decomposing dead fish and fish faeces, (2) fish perturbation of the soil-water interface which leads to release of fixed nutrients from soil to water and makes the soil porous for nutrients readily absorbed by the rice roots, (3) fish grazing on the photosynthetic aquatic biomass and other components of the system which aids in nutrient recycling and minimizes N losses (Cagauan, 1995). Moreover, bottom feeders are known to bring mineral and organic matter from the sediments into suspension through its feeding activities. This results in (1) increased water turbidity (Vromant et al., 2004) in the rice fields (2) aeration of rice field soils (Heckman, 1979) and P release from the sediment (Breukelaar et al., 1994) and (3) establishment of a contact between the benthic and pelagic compartments, which are otherwise fully separated. Fish/prawn culture in paddy fields can turn material and energy into fish/prawn production, accelerate the growth of rice and increase the solar energy fixation, thus raising the productivity of paddy fields (Mohanty, 2003). Fish acts as a bio-controller of insects, thus reduces the input cost of insecticide. Weeds compete with rice, as they need CO_2, H_2O and other nutrients for photosynthesis. However, fish helps in biological control of aquatic weeds, thus reduces the input cost of herbicide. Fish in a rice field can transform insoluble nitrogen in the soil in to a soluble state, which increases soil fertility. Cultivation of fish in rice field increases the amount of nitrogen in soil and the amount of nitrogen absorbed by rice plant, thus more nitrogen is transported to the rice grains, improving the quality of rice. The stirring movements of fish aerate the soil and improve its topsoil structure and porosity. This increases the dissolved oxygen level in the soil and elevates its oxidation and reduction potential during the period of rice growth (Mohanty, 2003a). Rice plants provide protection to fish/ prawn from predation by birds. Fish gets sufficient oxygen released by rice and phytoplankton for survival and growth. Fish diseases are rare in rice-fish culture, due to clear aquatic environment in presence of rice, high oxygen content and rich natural food that produce strong and disease resistant fish/prawn. After harvest of rice, the roots and remaining parts of straw (straw contain 9-13% cellulite, 1.5-3% potassium and 30-40% cellulose) provide organic matter and favours growth of microorganism, the ultimate natural food of fish/ prawn. The voiding of poultry/duck/animals could be recycled as fish feed and this could also increase the biological productivity of water. Addition of animal/bird droppings in water reduce the fish feed cost by 40% and fertilizer cost by 60-65%.

1.3 An on-farm Study

Keeping in view, the outstanding contribution of rice-fish farming to food and livelihood security, its importance in terms of landscape diversity, land and water management etc., WTCER (ICAR), Bhubaneswar had initiated an on-farm research (WTCER/03/89) on 'Deepwater high-density rice-fish culture' based on the principle of high initial stocking followed by phased harvesting. The selected study site (Khentalo village, Lat. $20^{0} 15^{/}$ N and Long. $86^{0} 03^{/}$ E) was one of the lowest productive areas of Orissa state, prone to chronic water logging problem. In this agricultural production system, traditional agriculture was intensified by inclusion of diverse on-dyke horticultural crops in integration with deep water rice-fish culture, and an attempt was tried for development of economically viable integrated agri-aquacultural production system for water-logged areas. This on-farm research was aimed at, to study the production performance of high-density deepwater rice-fish culture, impact of cull/selective harvesting on balanced standing crop and population structure of freshwater prawn *M.rosenbergii*, hydrologic and water balance component and finally the water productivity of the system.

2.0 MATERIAL AND METHODS

In a farmer's field at Khentalo village (Lat. $20^{0} 15^{/}$ N and Long. $86^{0} 03^{/}$ E) of Cuttack district, Orissa, India, 2.0 ha waterlogged area was converted into two units of deepwater rice-fish system (T_1 : rice-fish with cull harvesting and T_2 : rice-fish without cull harvesting) with another 1.0 ha adjacent land exclusively for deepwater rice (DWR) only (T_3), to study the impact of fish and prawn on rice yield. Only fish culture without rice (T_4) was also undertaken in another adjacent pond of 0.5 ha area, to study the economics and water productivity of the system. 50% of the land (T_1 and T_2) was excavated up to a depth of 100cm and the excavated soil was utilized for peripheral dyke construction up to a height of 2.5m (Fig 1). Deepwater rice variety *Durga* (CR 683-123) was transplanted in the unexcavated land (50% area, 5000m^2) of T_1 and T_2 and 100% area of T_3 plot during 3rd week of July in the 1st , 2nd and 3rd year for this study (2003-2006). Rice area under T_1, T_2 and T_3 were divided in to four sub-plots each. Rice was transplanted with a spacing of 20 X 20 cm (between rows and plants). The fertilizer application rate was 80:60:40 (N:P:K) ha^{-1}. 50% of N and full dose of P and K was applied as basal dose at the time of transplanting. The rest of nitrogen was applied at two equal splits during tillering and panicle initiation stages (30 and 60 DAT). Crop growth and yield parameters were recorded at regular intervals. No pesticide was used in the experimental plots to prevent fish mortality. Final yield and yield attributes of crops were recorded at the time of harvest. Standard agronomic and aquaculture package of practice was adopted.

Pre-stocking refuge (T_1 and T_2) and pond (T_4) preparation such as horizontal and longitudinal ploughing followed by application of lime ($CaCO_3$) @ 750kg ha^{-1}, raw cattle dung (RCD) @ 7000kg ha^{-1} as basal dose and fertilizer (Urea : Single Super Phosphate ::

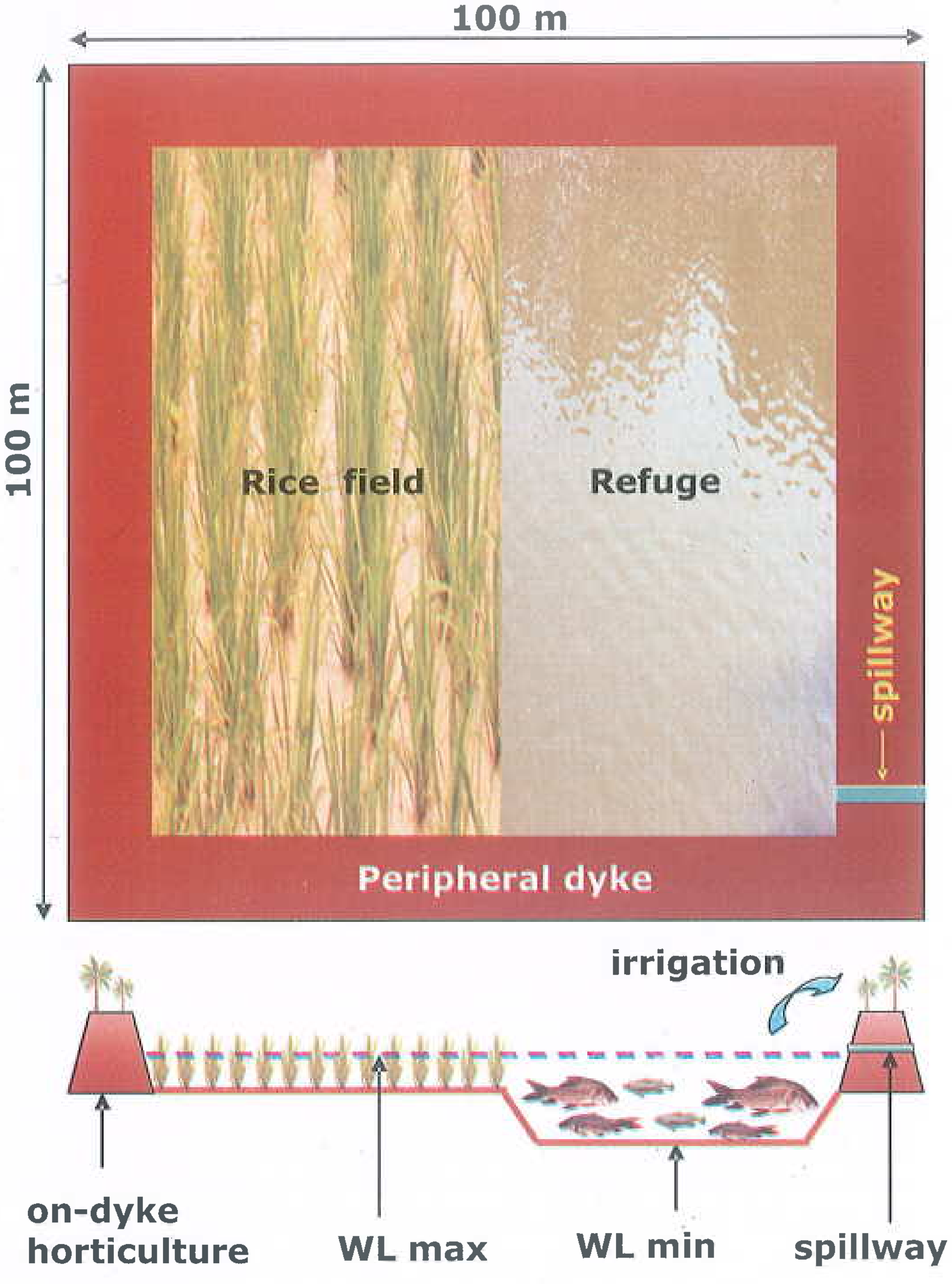


Fig.1 Lay out of deepwater rice-fish system (1 ha unit)

1:1) @ 3ppm was carried out prior to stocking. Seven days after refuge and pond preparation (3rd week of July), early fish fingerlings (3.0 - 4.8g Mean Body Weight) and prawn juvenile of *M. rosenbergii* (1.2g MBW) were stocked @ 1,00,000 ha^{-1} with a species composition of 25:25:15:15:20 (*Catla catla*: *Labeo rohita*: *Cirrhinus mrigala*: *Cyprinus carpio*: *Macrobrachium rosenbergii* :: 12500: 12500: 7500: 7500: 10000) in the excavated refuge ($5000m^2$) of T_1 , T_2 and in T_4. Supplemental feeding was provided with a ratio of 55:35:10 (rice bran: mustard oil cake: fish meal) @ 6%, 5%, 4% and 2.5% of MBW, twice a day, during 1st, 2nd, 3rd and 4th month to harvesting, respectively. Periodic manuring with RCD @ 500kg ha^{-1} and liming @ 200kg ha^{-1} were carried out at every 15 days interval to maintain plankton population in the eco-system. Periodic observation on water quality, soil quality, fish and prawn growth parameters, yield and yield components, hydrological and water balance related studies were carried out at regular intervals at the experimental site. Cull/selective harvesting of fish and prawn was undertaken after 120 and 165 days of stocking (DAS). Fish and prawn rearing continued for 210 days. After harvesting of rice and fish, a low duty second crop (black gram, *Phaseolus mungo*) was undertaken in the designated rice area of T_1 , T_2 and T_3. On the entire peripheral dyke of each unit, brinjal (*Solanum melongena*) and ladies finger *(Hibiscus esculentus)* was transplanted on both sides (800 numbers each) with a spacing of 50cm between plants. In the middle of the embankment, dwarf variety of Papaya and Banana were grown alternatively at a spacing of 1.5m as an additional component. Irrigation to this plants were given using the refuge/pond water.

Major physico-chemical parameters of pond water, e.g., dissolve oxygen (DO), temperature, pH, turbidity; total alkalinity, total suspended solids, CO_2 and salinity were monitored *in-situ* every day between 0700-0800 hours using standard method (APHA, 1995, Biswas, 1993) and were cross checked by Multi-parameter Water Analyzer (YK-611, Yeo-Kal Electronics Pty. Ltd., Australia). NH4+ was determined spectrophotometically with indophenol blue method while chlorophyll-a was determined using the acetone extraction method (Strickland and Parsons, 1972). Primary productivity using "Oxygen method" (APHA,1995), plankton estimation, nutrient analysis and monthly observations on soil quality (available-N, available-P, organic carbon and pH) were studied using standard methods (Biswas, 1993).

To estimate the food preference and feed intake pattern of cultured species, gut content analysis, degree of satiation (Mohanty et al., 2000), indices of electivity of different food component (Ivlev, 1961), frequency, abundance and matrix of dietary overlaps (Johnson,1999) were carried out. Every year, during the experiment, 18 numbers of each species were sacrificed for this purpose. Weekly growth study was carried out by sampling prior to feeding, so that complete evacuation of gut was ensured. Weekly mean body weight (MBW), per day increment (PDI), survival rate (SR%), biomass (kg), feed requirement, % feed used, feed requirement per day and apparent feed conversion ratio (AFCR) was estimated as described by Mohanty (1999).

To assess the output from the plot as a single unit, rice equivalent yield (REY) was computed considering the farm gate selling price of rice, fish fingerling, prawn and marketable fish as Rs.5.00, Rs.2.50, Rs.120.00 and Rs.50.00, respectively and the proportional area devoted to rice and fish cultivation. Economic indices of water productivity (net consumptive water use index, Rs. m^{-3}) were estimated as suggested by Boyd, 2004 and James et al., 2005. Ratio of the out put value to the cost of cultivation of the integrated farming system was estimated. The cost of excavated refuge/pond, considering the life span up to 15 years, which is a fixed cost, was added (depreciated cost) to the yearly variable cost of cultivation. The cost of excavated refuge/ pond was estimated to be Rs.1; 35,000 ha^{-1}. The operational cost includes: the cost of feed @ Rs. 14.00 per kg; fish seed @ Rs.200.00 per 1000 early fingerling; prawn seed @ Rs.0.5 per seed; raw cow dung @ Rs. 500.00 per 1000 kg; labour @ Rs.70.00 per man day; lime @ Rs.4.50 per kg and other cost such as cost of plant material, fertilizer etc.

3.0 RESULTS AND DISCUSSION

3.1 Rainfall analysis and Hydrology

Rainfall analysis of the study area was carried out for a period of 31 years (1975-2005). From the analysis it was observed that the annual rainfall varies between 951.6 mm (1996) to 2218.7 mm (2001) with 55% of all the years have rainfall below normal. 84.1% of the total rainfall occurs between June to October. Normal rainy days in a year are 105, maximum was 129 (1983), and minimum was 86 days (1979). Onset of effective monsoon is 15th June, earliest is 7th June, latest is 23rd June (based on both mean and median). Similarly cessation of effective monsoon is 8th October, earliest is 26th September, and latest is 20th October based on mean; and 10th October, 28th September, and 22nd October is normal, earliest and latest date for cessation of monsoon based on median. The weekly maximum, minimum and normal rainfall observed during 1975-2005 is given in Figure 2.

The maximum rainfall observed in a week had two distinct peaks. One refers to heavy rainfall during 19th standard meteorological week in May 1995 amounting 472 mm which was a record. The second peak refers to last week of October (44th standard meteorological week) in 1999 during the super cyclone in Orissa amounting 477 mm. Besides this heavy weekly rainfall is expected between 27th to 34th week every year.

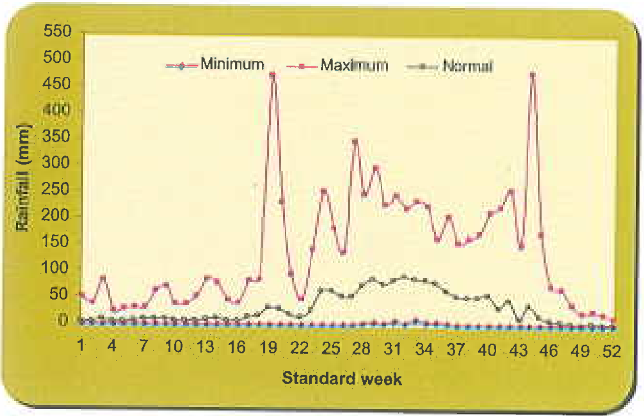


Figure 2. Weekly maximum, minimum and normal rainfall observed during 1975-2006

The comparison of weekly rainfall and evaporation is given in Figure 3, where it is observed that the rainfall is higher than evaporation during 24th week to 43rd week causing water congestion and excess water is to be stored in ponds for aquaculture and for irrigating *rabi* crops including vegetable and other cash crops. Where as evaporation is higher than rainfall during 44th week to 23rd week indicating irrigation is required if any crop is to be grown during this period.

The weekly rainfall at different probability level is given in Figure 4. Depending upon the requirement rainfall at different probability level would be considered for design of different structures such as field bunds, ponds, emergency spill way, drainage system etc.

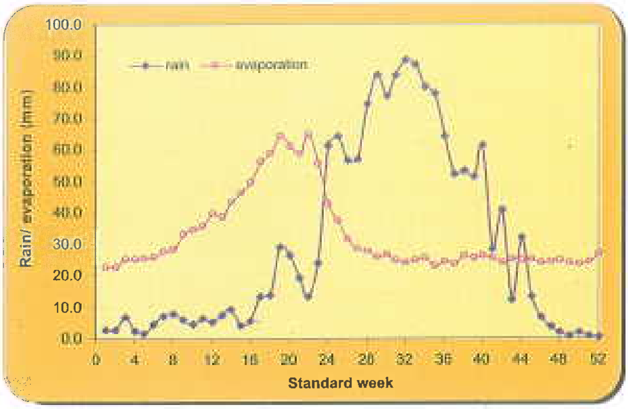


Figure 3.The comparison of weekly rainfall and evaporation

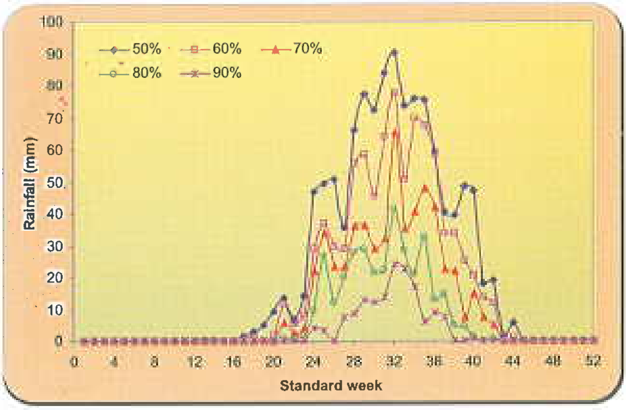


Figure 4. Weekly rainfall at different probability level at Khentalo.

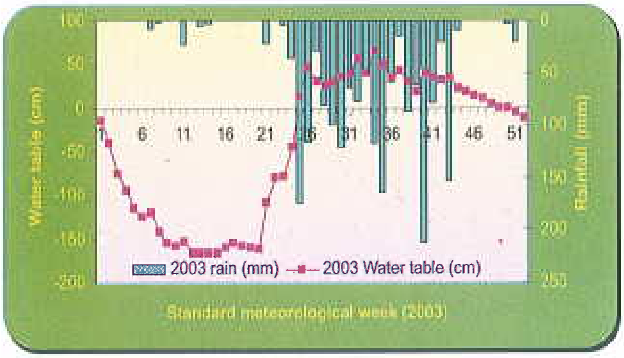


Figure 5. Rainfall & water table fluctuation during different standard meteorological week in 2003-4

Water table fluctuation in surrounding fields of the pond

During 2003, the water level went up to as high as 65 cm above ground surface in 34th standard week and remained above the surface during 25th to 48th week. During driest period the water table went down to 167 cm below ground level (Figure 5). This is a precarious water logging condition prohibiting growing of any other crop than paddy with very low return. Hence an alternative approach of high-density integrated rice-fish culture was taken up due to which there was a slight change in hydrological situation of the study site. The constructed refuge and pond acted as drainage system and water used for irrigating the horticultural and plantation crops on the bund helped in reducing the water table.

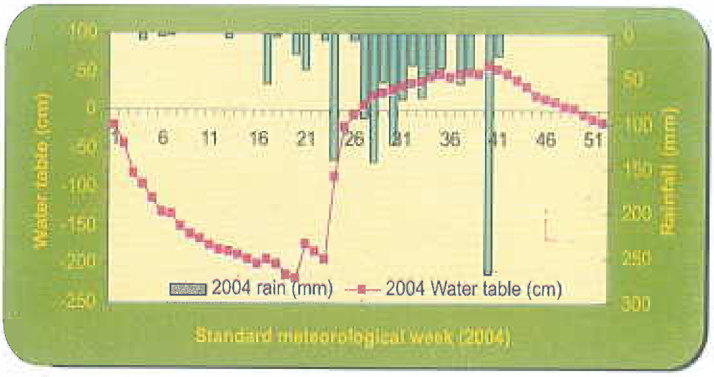


Figure 6. Rainfall & water table fluctuation during different standard meteorological week in 2004-5.

The comparison of rainfall in different standard week and corresponding water table in the surrounding fields of the pond system during 2004 and 2005 is given in Figure 6 and Figure 7 respectively.

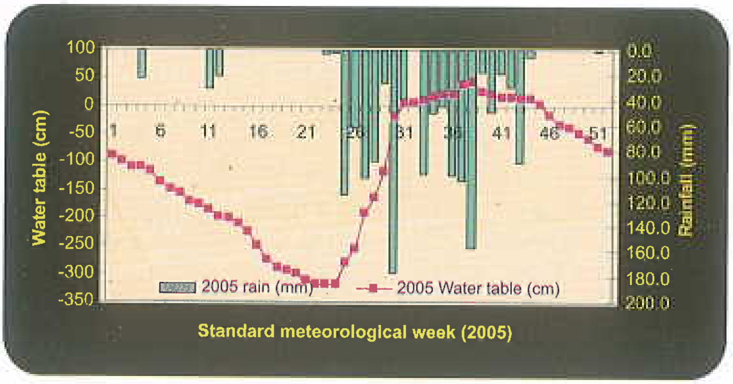


Figure 7. Rainfall & water table fluctuation during different standard meteorological week in 2005-6.

The total rainfall obtained during 2004 is about 1360 mm out of which about 1200 m rainfall was received during monsoon (mid-June to mid-October). The water level in the field was as high as 56 mm during 1st week of October which correspond to the highest rainfall obtained during 40th standard meteorological week. Water table remained above surface for more than 30 cm height for about 12 weeks during 2004, thus restricting to moderate paddy yield. However during driest period the water table went down to as low as 220 cm during mid-May (14th standard week). In comparison to 2003 the water table regime remained in a better condition both in terms of depth of water table during driest period and less water ponding above surface during monsoon.

During 2005, the maximum water level above ground rose up to 40 cm in 3rd week of September due to heavy rain during two consecutive weeks (104 mm during 37th week and 157.6 mm during 38th week) but the over all water level was less during peak monsoon i.e., during July and August in comparison to 2003 and 2004, thus helping paddy to grow better. During summer season the water table went as deep as 3.2 m below ground level in comparison to 1.67 m in 2003 and 2.20 m in 2004. Hence the area surrounding the refuge/pond has reclaimed and free from water logging which has resulted due to excavating refuge/ponds for psciculture and using pond water for irrigating on-dyke horticultural crops. The comparison of water table fluctuations during three year of study (2003-2005) is given in Figure 8. During 2003 the water table remained 30 cm above surface from 26th week to 38th week, where as during 2004 the same condition prevailed during 32nd to 43rd week. The maximum depth of water above surface for a longer period was observed during 2003 thus giving a low paddy yield, however it was better in comparison to previous years when there was no intervention before 2003. During 2005 the water table remained well below 2m from ground surface during dry months, thus creating space for recharge during monsoon. This resulted less stagnation of water during monsoon. The ponding water was more than 30 cm for only 2 weeks, thus the paddy yield was enhanced.

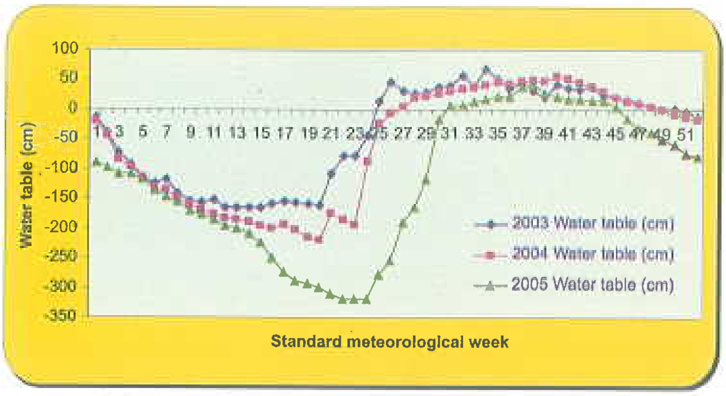


Figure 8. Comparison of water table fluctuation during 2003-4 to 2005-6.

3.2 Excess water conservation and management

During 2003 and 2005, the annual rainfall was more than average and during 2004 it was nearly normal. The monthly rainfall scenario of the experimental site during monsoon season is presented in Fig. 9.

In 2003, the monthly rainfall during all monsoon months were more than 30 years average, where as in 2004, all months received slightly less rainfall than average. Again in 2005, July, August and September months received more rainfall than normal where as in June and October it was deficit rainfall. However, in all these cases, the water level in the refuges/pond were observed to be sufficient enough (> 1 m) till end February for short duration fish culture (Table 2).

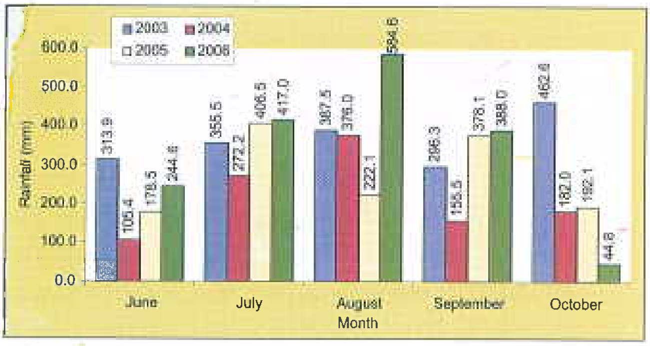


Fig. 9. Monthly rainfall scenario of the study site during *Kharif* season

The above table indicates that in all three years of experimentation the depth of water available in the refuge was more than the desirable depth for better aquaculture activities in the whole growing period of seven months. So availability of water in the refuge was

Table 2. Monthly average depth of standing water in the refuge during the experimental period

Year	Water depth in refuge (cm)						
	August	September	October	November	December	January	February
2003-04	162	158	145	126	116	105	98
2004-05	149	156	158	127	110	98	90
2005-06	136	140	145	122	115	106	95
Average	149	151	149	125	114	103	94

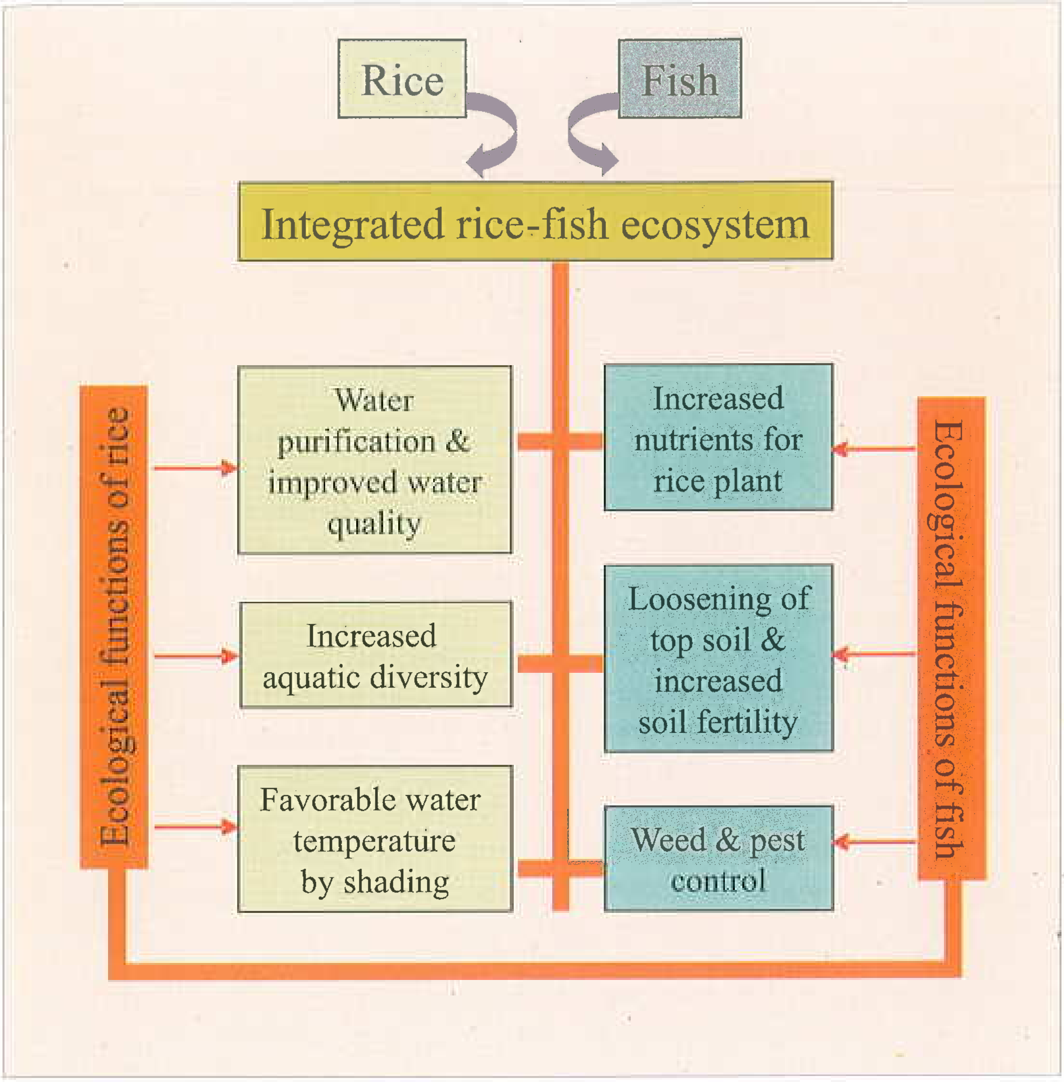
not a problem during the study period. The water available in the surrounding paddy field was sufficient in the whole study period. There was no need of irrigating the *kharif* paddy. However considering the availability of water in the refuge, if needed life saving irrigation could easily be provided to paddy and other crop during less rainfall year. Also vegetables grown on the dyke were irrigated using the refuge water at the time of need during the whole study period.

3.3 Soil quality

The experimental area with respect to soil type falls under alluvial zone. Soil analysis shows that textural class is clay having acidic pH (6.6-6.8). The composition of sand, silt and clay was 36.6, 19 and 44.4 % respectively. Organic carbon (%) in soil, available – N and P in soil (mg 100 g^{-1}) ranged between 0.16-0.19, 7.9-10.1 and 1.28-1.63 respectively at the initial stage of intervention, which improved further, with the advancement of crop cycle (Table 3) probably due to (1) additional nutrients from fish feed and fish faeces, (2) fish grazing on the photosynthetic aquatic biomass and other components of the system which aids in nutrient recycling and minimizes N losses (Cagauan, 1995) and helps in P release from the sediment (Breukelaar et al., 1994). However, no distinct trend between the treatments was observed.

3.4 Rice field ecosystem : An integrated system with complex interactions

In rice-fish farming system, the aquatic environment is largely determined by the growth of rice crop (Vromant and Chau, 2005). Rice fields have a unique limnology not mirrored by any natural aquatic habitat although they share some features of marshes, shallow lakes and ponds (Fernando, 1995). It is a temporary aquatic environment subject to large variation in pH, dissolved oxygen and nutrient status due to frequent use of organic/ inorganic fertilizers, aqua drugs and feed. The extreme instability of the rice agro-ecosystem, the rapid fluctuations inherent to the crop cycle, and the artificial and temporary nature of the rice fields render it a difficult ecosystem to study. Non-biological factors (water, soil, heat, air and light) and biological factors (plant, animal and microorganisms) are always interrelated and interdependent. They form an ecosystem of unilateral functions. Change in one factor triggers a chain of changes within the ecosystem. The rice land ecosystem is an anthropogenic system where rice is predominant. In the biological community of the rice field ecosystem weeds, plankton, humus and



bacteria are the primary producers. These primary producers and rice undertake energy conversion and storage in a similar and competitive manner. Both rice and primary producers absorb solar energy, carbon dioxide and nutrients from soil and water to manufacture organic matter by photosynthesis and they convert, transport and store energy. This competition among the biological communities, degrades the growing environment and increases factors that are unfavorable to rice growth. However, presence of fish in the rice field creates a conducive environment for rice to grow.

The principle of symbiosis and mutual-benefits of ecosystems, and the principle of the food web, are applied to optimize the current ecosystem comprising fish, rice and aquatic microbes, so that each subsystem takes advantage of and promotes one another. Consequently, the production of both fish and rice is increasing and their respective economic returns are increased. In this integrated ecosystem, rice provides shade for fish, especially in summer when the water temperature in the field can be lowered to a certain extent. The decaying leaves of rice offer favorable conditions for the multiplication of microorganism, which are the main fish feed. Fish, on the other hand, help to loosen the surface soil on which rice is planted, bringing about increased permeability and oxygen content of the soil, as well as enhanced vitality of microbes. Thus, the decomposition of nutrients in the soil is quickened, making it easy for rice to absorb. Fish make another contribution by preying on pests and weeds. Moreover, their excreta serve as both a natural fertilizer for rice and enrichment for soil. In this way, both fish and rice are positioned in a sound ecological environment with positive circulation systems, strengthened integrated functions and enhanced production abilities. Fig. 2 shows the integrated system with complex interactions.

3.5 Mutualism of rice and fish

Some of the ecological requirements of rice and fish are similar and this provides the basis for their synchronized growth under one ecosystem. Water is a prerequisite for raising fish and for growth and development of rice. Water, as a component of plant cytoplasm, is also indispensable for the synthesis of organic matter in plants and for the absorption and transfer of nutrients. Further, when fish, especially herbivorous and omnivorous fish are introduced into the rice fields, they add a new link to the existing food chain. They feed on primary producers and therefore reduce energy losses, improve the use of photosynthetic products and promote transformations in the rice field ecosystem that increase the carrying capacity of the rice field.

In rice-fish fields the rice stabilizes water temperature and quality, therefore, provides an environment that is conducive to the reproduction of natural fish food organisms. These primary producers convert solar energy into food energy that is required by fish for their survival. The sequential relationship in the distribution of rice and fish is apparent. Fish in rice field feed on available plankton (that compete with rice for fertilizer), weed (that compete with rice for nutrients), insect and bacteria (that harm rice plant) and mosquito larvae (harmful to humans).

Fish assimilate only 3-4% of these feeds and discharge the rest in to rice field that acts as manure. Because the fish consume phytoplankton, zooplankton and weeds that compete with rice, they play an important role in recovering lost energy and adjusting energy flow. When they swim in water, release carbon dioxide and that increases the amount of carbon available to the plants. They also break the soil surface and oxidize layers of soil, which increases the supply of oxygen, promotes root growth and tillering capability of rice plant. It is reported that under this system, paddy yield has been increased by 8-47% (8-25% in India). The increase in the yield of paddy probably results due to better aeration of water and greater tillering effect caused by the presence of fish. The excreta of fish, left over supplemental feed and additional fertilizer used also help in increasing the soil fertility and productivity.

Rice-fish mutualism is therefore, the best way to maximize the output of the ecological system, that turn material and energy into fish production, accelerate the growth of rice and increase the solar energy fixation, thus raising the productivity of paddy fields. Integrated rice-fish farming not only enhance productivity, but also generate employment opportunity, increase income and provide nutritional security to resource poor farming community and distribute the risk (both biological and economical), since two subsystems are involved instead of a single commodity farming system.

3.6 Agricultural Crop Management

3.6.1 Growth and yield performance of rice

Rice variety 'Durga' (CR-683-123) was grown under three different treatments (T_1: rice-fish with cull harvesting; T_2: rice-fish without cull harvesting and T_3: only rice mono-crop). The highest grain yield was recorded in T_1, which is significantly superior to that of T_3 and T_2. This was mainly contributed by higher number of panicles/m^2 (139.5) and number of filled grains/panicle (111.5). Percentage increase in grain yield over rice mono-crop was however, higher in T_1 (25%) followed by T_2 (16.9). Less number of panicles (122.2/m^2) and number of filled grain (98.5/panicle) in rice mono-crop was probably due to the absence of fish and prawn in the field which helps in improving soil fertility, recovering lost energy, adjusting energy flow by consuming plankton, weeds, insect and bacteria that compete with rice for nutrient. Further, fish helps in enhancing carbon available to plant by releasing carbon dioxide and break the soil surface, oxidize layers of soil that increases the supply of oxygen to promote root growth and tillering capability of rice plant. Since fish in rice field also helps in improving the physico-chemical properties of arable layer soil of paddy field, enhancing growth period of rice, increasing dry matter and LAI of different growth stages, increasing area of top three leaves which improves photosynthesis rate and grain filing and deterring the degeneration of leaves function (Yang et al 2006); growth and yield performance of rice was enhanced in T_1 and T_2 (Table 4) than T_3 (rice mono-crop). Among T_1 and T_2, comparatively higher yield was recorded in T_1 (3.25 t ha^{-1}) probably due to lower chlorophyll-a and plankton density (Table 3) that minimized the competition for nutrient with rice plant, which agrees to the findings of Heckman,1979 and Kropff et al, 1993.

3.6.2 Fertilizer application, weed management and IPM

Application of fertilizer and chemicals

Application of fertilizers, organic or inorganic, benefits both rice and fish. The presence of adequate nutrients increases the growth of phytoplankton, which may be consumed directly by the fish or indirectly through supporting zooplankton production. The growth and development of paddy and the fish is greatly influenced by the kind and quantity of fertilizers applied and the method of application. Nitrogen, phosphorous and potassium

Table 3. Minimum and maximum average values of water and soil quality parameters in different treatments of deep-water rice-fish integration system

PARAMETERS	Rice-fish system with phased harvesting (T_1)	Rice-fish system out with phased harvesting (T_2)	Only rice (T_3)
pH	6.7-8.6 (7.63)	6.9-8.5(7.31)	6.7-8.1 (7.52)
Dissolved Oxygen (ppm)	3.8-9.3 (5.1)	3.3-8.4(4.9)	4.4-8.9 (6.1)
Temperature (^{0}C)	27.8-31.2 (28.4)	27.7-31.3(28.4)	27.9-31.5(28.7)
Total alkalinity (ppm)	79-117 (106)	68-109(94)	73-107 (88)
Dissolved Organic Matter (ppm)	1.3-6.2 (3.2)	1.45-4.8(3.4)	0.55-3.6 (2.6)
TSS (ppm)	160-362 (213)	132-297(225)	60-257 (177)
NH_4^+ water (ppm)	0.31-0.88 (0.65)	0.34-0.97 (0.68)	0.41-0.91 (0.59)
Chlorophyll-a (mg m^{-3})	20-51.5 (36.7)	21.1-62.2 (41.1)	18.8-31.3 (22.3)
Total plankton (units l^{-1})	$4.4x10^3$-$2.3x10^4$ ($1.4x10^4$)	$2.9x10^3$-$6.7x10^4$ ($3.3x10^4$)	$9.4x10^2$-$1.8x10^4$ ($7.3x10^3$)
Nitrite – N (ppm)	0.009-0.06 (0.03)	0.012-0.072(0.037)	0.011-0.07(0.033)
Nitrate – N(ppm)	0.06-0.51 (0.36)	0.05-0.49(0.37)	0.16-0.61 (0.36)
Phosphate – P (ppm)	0.07-0.34 (0.21)	0.06-0.33(0.21)	0.13-0.54 (0.26)
Available-N in soil (mg 100 g^{-1})	18.1-21.1 (19.8)	17.9-21.6(19.3)	20.1-21.9 (20.3)
Available-P in soil (mg 100 g^{-1})	1.3-2.69 (2.21)	1.28-2.93(2.23)	1.63-2.89 (2.11)
Organic carbon in soil (%)	0.44-0.76 (0.61)	0.49-0.82(0.64)	0.57-0.75 (0.63)
Soil pH	6.6-7.1 (7.04)	6.8-7.1(7.01)	6.8-7.1 (6.94)

* *Figures in parenthesis represent mean values*

Table 4. Rice yield attributes in deepwater rice-fish system

Treatments	Rice yield (t ha^{-1})	% Increase in grain yield over rice monocrop	Number of panicles/m^2	Number of filled grain/ panicle	Test weight (g)
Rice mono-crop (T_3)	2.6 (3.18)	-	122.2	98.5	24.75
Rice-fish without phased harvesting (T_2)	3.04 (3.61)	16.9	130.2	106.2	25.6
Rice-fish with phased harvesting (T_1)	3.25 (3.94)	25	139.5	111.5	25.8
CD (0.05)	*0.14 (0.136)*	-	*3.5*	*3.2*	*0.322*

* *Figures in parenthesis represent straw yield (t ha^{-1})*

Table 5. Nutrient composition of different organic manures used for aquaculture.

Manure	Nutrient composition (%)			Manure	Nutrient composition (%)		
	N	P_2O_5	K_2O		N	P_2O_5	K_2O
Animal Origin				**Plant Origin**			
Cattle dung	0.5	0.4	0.2	Groundnut cake	6.5	1.0	1.0
Pig dung	0.6	0.6	0.4	Mustard cake	4.5	1.5	1.6
Poultry dropping	1.7	0.9	0.7	Mahua cake	2.5	0.8	1.9
Duck dropping	0.9	0.5	0.6	Neem cake	5.2	1.1	1.5
Farm Yard Manure	0.6	0.5	0.1				

needed by the paddy are also nutrients required by the planktonic and benthic organisms, which are in turn, the natural food of fish. But too much inorganic fertilizer is also toxic to fish. The improved technique of fertilization is to use nutrient rich organic manures (Table 5) as much as possible and inorganic fertilizer as little as possible. Organic manure should be applied after fermentation. Seventy percent of the total manure should be applied as basal and rest as supplementary manure, which should be applied in small amounts frequently.

Experiments in China indicate that the organic nitrogen, alkaline nitrogen and total nitrogen in the soil are consistently higher in fields with fish than in the control fields without fish (Wu 1995). Wu attributed this to the fact that fish in the rice field consume weeds and are able to assimilate 30% of the weed biomass. The rest is excreted that helps maintain soil fertility since nutrients, otherwise locked up in weeds, are released. Further experiments showed that rice-fish plots require less fertilizer that rice-only plots. On average the control plots used 23% more fertilizer than the rice-fish plots (Li et al 1995). In summary, the Chinese experiments indicate that less, not more, fertilizer is required in rice-fish farming.

Fertilizer applied in rice-fish farms by incorporating the nitrogen fertilizer thoroughly in the soil during land preparation results in higher rice yields than when broadcast on the surface. No difference has been found between applying the phosphorus fertilizer on the surface or incorporating it in the soil. However, surface application is believed to be better for promoting plankton growth in the water. Split applications of phosphorus may be better for sustained plankton production without hampering rice production as long as they are made before tillering. If applied at a later time, this should be on top of the normal requirements for rice. An application rate of 30-50 kg P_2O_5-ha^{-1} is often reported as optimum for algal growth.

Organic fertilizers benefit both rice and fish. In addition to nutrients, the particles can also act as substrates for the growth of epiphytic fish food organisms. Animal manure should be considered as an input to benefit the fish in addition to inorganic fertilizers applied primarily for the rice (Sevilleja et al. 1992). Manure should be applied several weeks before transplanting and the fields kept flooded for complete decomposition and to avoid any toxic effects. Fertilization is a complex issue and varies greatly depending on the particular location. Providing general statements runs the risk of over simplifying the issue, but there is evidence that nutrients are more efficiently utilized in rice-fish systems compared to rice-only systems, this effect being more enhanced particularly on poorer and unfertilized soils where the effect of fish may be greatest (Halwart 1998).

Although fish in rice fields can eat some of the pests and play a role in the biological control, they cannot totally replace insecticides, so chemical control is needed. However, chemical plant protection should be avoided to prevent fish/prawn mortality. In fact, in waterlogged situation, insecticide hardly works as high standing water dilutes the concentration. But in emergency, chemicals that have low toxicity, low residue, high effectiveness and a broad spectrum can be applied. Chemicals in powder form should be applied in the early morning hours, while there is still dew around, and application of sprays should be delayed until after the due fades. Nowadays, the splashing method is adopted with good results especially when the rice grows tall. It is always economical and advisable to reduce the water level before application of fertilizer and chemicals.

Weed management

There are several practical options in controlling weeds in rice fields: land preparation, water depth variation, mechanical weeding, herbicide use and stocking of herbivorous fish. Mechanical weeding is perhaps the most frequently used way of controlling weeds. It is, however, a very labor-intensive way of controlling weeds and as such often carries a high opportunity cost. Herbicides are used extensively, but are not considered a serious problem in rice-fish farming. If a herbicide is applied, it is normally done immediately after transplanting. Fish are stocked 10 to 14 days after application. Further it is also possible to select a herbicide which can be tolerated by fish even at relatively high levels.

Introducing fish to the rice field can reduce the amount of weeds in several ways. To the herbivorous species of fish, weeds are part of their diet. To bottom feeding species, weeds just happen to be in the way. In the process of looking for food, the muddy bottom of a rice field is tilled giving little chance for the submerged weeds to anchor their roots in the soil thus affecting their growth and proliferation. In China, fish have been found to be more effective in weed control than either manual weeding or use of herbicides. The introduction of fish reduced the amount of weeds in one rice field from 101 kg to only 20 kg after five weeks, while in an adjacent rice field with no stocked fish the weed biomass increased from 44 kg to 273 kg during the same period (Wu 1995).

Integrated Pest Management

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

Integrated pest management encompasses all four management options outlined above and attempts to optimize their use. The use of chemicals is often cited as one of the major constraints in the popularization of rice-fish farming. Yet stocking fish in rice fields actually reduces pest infestation, and thus also reduces if not eliminates the need for application of herbicides and insecticides and particularly molluscicides where snail predatory fish are cultivated. The practical and economic advantages of using fish instead of chemicals are often obvious. The effectiveness of fish as a bio-control agent depends on how well they are distributed within a rice field. If fish stay mostly in the pond refuge then they cannot be effective in controlling rice pests. In such a situation, the use of pesticides as well as other control methods should be considered based on the potential costs and losses in terms of rice yield and fish harvest. The important characteristics to be considered in the selection of any pesticide to be applied in a rice-fish farm can be summed up as fallows:

- Relative safety to fish and effective against the target insect species
- Should not accumulate or persist in rice and should be metabolized into non-toxic compounds and excreted by fish should either volatize, bio-degrade or chemically degrade shortly after its application

3.6.3 On-dyke horticulture and *Rabi* crop

The dykes to be constructed for preventing escape of fish from the integrated system may be used for growing vegetables and other fruit trees like papaya and banana to make the system more economically viable. Vegetables such as gourd, radish, brinjal, leafy vegetables during pre and *kharif* season and vegetables such as tomato, french beans, radish, bitter gourd, cucumber, cauliflower, cabbage, brinjal, pumpkin and leafy vegetables (coriander, amaranthus and Indian spinach) can be grown during winter. Vegetables such as snakegourd, bittergourd, ridgegourd, bottlegourd or ashgourd can be grown throughout the year on raised platforms. However, in this experiment However, in this experiment, brinjal (*Solanum Melongena*) and ladies finger (*Hibiscus esculentus*) were transplanted on both sides of the peripheral dykes (800 numbers each) with a spacing of 50 cm between plants. In the middle of the embankment, dwarf variety of papaya and banana were grown alternatively at a spacing of 1.5 m as an additional component. Irrigation to these plants was given using the refuge water. Between these two horticultural plants, banana performed the best in the forms of yield and survival. The average yield of brinjal, ladies finger, banana and papaya was 240 kg, 185 kg , 92 bunches and 435 kg per hector of rice-fish unit.

The average yield of post-paddy second crop (black gram) was 0.78 t ha^{-1}. Before intervention the study site was only a mono-cropped area. However, after intervention the cropping intensity of the site increased from 100% to 150% due to low duty second crop after harvest of fish.

3.7 Aquaculture and its Management

3.7.1 Water quality in relation to fish production

Water quality is a dynamic property of a system affected by chemical, biological and physical factors, which ultimately influences the aquatic environment and production of rice based farming systems. Water quality parameters of the most sensitive component of the farming system are required to be realized. Management of water quality is a daily monitoring process, which includes the behavior of fish, nature of water and inputs of diligence from farmers. Since scientific water quality management and maintenance of tolerance limit (Table 6) of hydrological parameters cannot be expected at farmers end, the minimum adoptable techniques for water quality monitoring at farmers end should be encouraged. This includes fortnightly liming @ 100-150 kg/ha, manuring with raw cattle dung @ 500 kg/ha to maintain plankton bloom, which in turn regulates dissolved oxygen and pH of the eco-system. As these two parameters are too much critical for fish growth and survival, utmost care must be taken for bloom management. As the optimum ratio of phyto and zooplankton is 10:1, periodic estimation of plankton is essential. In case of plankton crash, re-inoculation should be carried out followed by fertilization with Urea + SSP (1:1) @ 3-4 ppm or systematic water replenishment in case of excessive bloom build up. Further to maintain a clear aquatic environment, meal to meal feed management is essential in reducing the organic load in the system that affects water quality.

In this experiment the recorded mean minimum and mean maximum values of various water and sediment quality parameters are presented in Table 3. Total suspended solid (TSS) and dissolved oxygen (DO) concentration showed a decreasing trend with the

Table 6. Suggested water quality criteria for fish rearing

Chemical parameters	Tolerance ranges
Ammonia (NH_3)	<0.125 ppm (un-ionized form)
Calcium	10.0-160.00 ppm
Carbon dioxide	0.00 to 10 ppm
Chlorine	0.03 ppm
Hydrogen sulphide	0.002 ppm
Iron (total)	0.0 to 0.15 ppm
Nitrate (NO_3)	0.0 to 3.0 ppm
Nitrite (NO_2)	0.1 ppm in soft water,0.2 ppm in hard water
Dissolved oxygen	5.0 -9.0 ppm
pH	7.5 to 8.5
Phosphorous	0.01 to 3.0 ppm
Total suspended solids	80.0 ppm or less
Total Alkalinity	90-170 ppm
Water colour	Green to brown
Temperature	26-32^0 C

advancement of rearing period while, slightly higher values of nitrite, nitrate, ammonia and total alkalinity were recorded towards the later part of the experiment. At any given point of time, the remaining water quality parameters and plankton population did not register any specific trend between the treatments. Mainly diatoms and green algae dominated phytoplankton population while zooplankton population by copepods and rotifers. In all the treatments, average primary production in the first month of cultivation ranged between 87.6-137 mg C m^{-3} h^{-1}, which improved further (407.5 ± 38.3 mg C m^{-3} h^{-1}) with the advancement of rearing period. Low primary production in the initial phase of rearing was probably due to fixation of nutrient ions by suspended soil/clay particles as well as rich organic matter (Mohanty, 2003). In general water reaction process is low during monsoon (July-August) due to dilution of alkaline substances or dissolution of atmospheric CO_2.

From fish rearing point of view, various hydro-biological parameters prevailing in different treatments were within optimum ranges and did not fluctuate drastically. This was probably due to similar levels of input in all the treatments in the form of organic manure, inorganic fertilizer and periodic living. The decreasing trend in DO in all the treatments (except rice mono-crop) with the advancement of fish rearing period, attributed to fluctuation in plankton density and gradual increase in biomass, resulting in higher oxygen consumption. Most warm water fish species require minimum DO at 1 ppm for survival, 3 ppm for comfort and 5 ppm for ideal growth and maintenance (Yaro et. al., 2005). However, in the present study DO level did not drop below 3.3 ppm in any treatment. Fish decrease the DO and pH value compared to rice mono-crop, especially when supplemental feed is given. Moreover, fish stimulate the growth of phytoplankton and increased chlorophyll-a concentration (Frei and Becker, 2005). Gradual increases in nitrite, nitrate, ammonia were attributed by intermittent fertilization, increased level of metabolite and decomposition of unutilized feed in absence of water replenishment (Mohanty et. al., 2004).

The most important factor limiting aquatic photosynthesis in rice fields is the shading by the growing rice biomass (Mustow, 2002). Besides the competition for light, rice also competes with the field water's photosynthetic active biomass (PAB) for available nutrients, especially N, the most limiting nutrient in the rice fields (Heckman, 1979 and Kropff et al., 1993). At the onset of the experiment, the high pH values (7.3-7.6), together with high dissolved oxygen (6.6-7.2) and chlorophyll-a values (36-42.2) suggest that an autotrophic pathway was dominate within the aquatic phase of the rice fields. However, with the increase in rice biomass, the chlorophyll-a concentration (20.4-24.6), NH_4^+ (0.31-0.34), pH (6.7-6.9), dissolved oxygen (3.3-4.4) decreased which indicate a reduced aquatic photosynthesis and suggest that the autotrophic pathway lost importance. With increasing rice biomass, surface feeder (*Catla catla*) and column feeders (*Labeo rohita*) gradually switched from feeding on plankton/ algal biomass to supplemental feed and to a diet primarily composed of detritus (Table 12 and 13), a process which results in interspecific competition with bottom feeders (*Cirrhinus mrigala*, *Cyprinus carpio* and *Macrobrachium rosenbergii*) which agrees to the findings of Chapman and Fernando (1994) and Vromant et. al., (2004).

In general, poor growth performance of cultured species takes place at pH < 6.5 (Mount, 1973) while, higher values of total alkalinity (> 90 ppm) indicates a better productive eco-system and increased plankton density, reflects higher nutrient status of the water body. The availability of CO_2 for phytoplankton growth is related to total alkalinity (Mohanty, 2003), while water having 20-150 ppm total alkalinity produce suitable quantity of CO_2 to permit plankton production. However, the recorded minimum and maximum range of total alkalinity during the experimental period (Table 3) was 68-117 ppm respectively, which was maintained due to periodic liming. Plankton density has always a profound effect on water quality having direct relationship with fish production (Simth and Piedrahita,1988 and Yaro et. al., 2005). In this experiment, fluctuating trend in plankton density (7.3×10^3 – 3.3×10^4) was recorded in different treatments (Table 3), which ultimately reflected the fish and rice yield in T_1 and T_2 (Table 7). Sediment characteristics of different treatments were however, indicating of a medium productive soil group (Banerjee, 1967).

Table 7. Treatment-wise rice, fish and rice equivalent yield (average of three experimental years)

Treatment	Rice area (m^2)	Refuge/ pond area (m^2)	Total area (m^2)	Rice yield (t ha^{-1})	Fish yield (t ha^{-1})	REY (t ha^{-1})
Deep water rice mono crop	10000	-	10000	2.6	-	2.6
Rice-fish (no phased harvesting)	5000	5000	10000	3.04	6.1	35.5
Rice-fish with phased harvesting	5000	5000	10000	3.25	6.96	38.5
Only fish & prawn culture with out phased harvesting	-	5000	5000	-	5.6	58.0

* Farm gate selling price of rice, fish fingerling, prawn and marketable fish was Rs.5.00, Rs.2.50, Rs.120.00 and Rs.50.00, respectively.

3.7.2 Impact of selective harvesting on growth, survival and yield of fish and prawn in rice-fish system

At a fixed stocking density (early fish fingerling of 3-4.8 g mean body weight and prawn juvenile of 1.2 g mean body weight stocked @ 1,00,000 ha^{-1}), faster growth rate was recorded for *Catla catla* followed by *C. Carpio* and *C. Mrigala* (Table 8) in rice-fish culture with phased harvesting (T_1) while in rice-fish culture without phased harvesting (T_2), faster growth rate was recorded for *C. carpio* (Fig.11 and 12). Similarly the growth

Table 8. Details of cull harvesting at different days after stocking (DAS) in rice-fish system

Species composition (25:25:15:15:20)	CULL HARVESTING						Final survival rate (%)
	1st cull (120 DAS)		2nd cull (165 DAS)		Final harvesting (210 DAS)		
	MBW (g)	NH	MBW (g)	NH	MBW (g)	NH	
Catla catla	66.7	4000^1	192.6	2000^2	387.5	1008^2	56.06
	(53.5)	–	(122.5)	–	(178.5)	(4113^2)	(32.9)
Labeo rohita	39.6	3000^1	98.4	3000^1	205.0	1690^2	61.52
	(27.2)	–	(89.5)	–	(101.0)	(6720^2)	(53.76)
C.mrigala	44.0	2000^1	145.0	1500^2	275.0	1807^2	70.76
	(43.3)	–	(115.0)	–	(185.5)	(4297^2)	(57.29)
C. carpio	57.7	1000^1	175.5	1500^2	340.0	833^2	44.44
	(58.0)	–	(140.2)	–	(217.8)	(2734^2)	(36.45)
M. rosenbergii	28.8	1500^3	52.2	3500^3	78.2	630^3	56.3
	(27.3)	–	(43.5)	–	(53.0)	(4669^3)	(46.7)

*MBW - mean body weight, NH - number harvested, ¹sold as fingerling @ Rs.2 .50/pc, ² sold in market @Rs. 50/kg, ³sold in market @ Rs. 120/kg. * Figures in parenthesis represent results of rice-fish culture without phased harvesting.*

performance of *M. rosenbergii* was much faster in T_1 than T_2. Impact of phased harvesting on overall growth performance and yield of fish and prawn (Table 9) was reflected in faster growth of all species after 120 days of rearing (Fig.11) and higher yield in T_1 (14.1% increase over T_2). Similarly higher survival rate and apparent feed conversion ratio was also recorded in T_1 (rice fish culture with phased harvesting) than T_2 (rice-fish culture without phased harvesting). Condition factor (ponderal index) of cultured species was less than 1.0 (0.87-0.97) at the initial three weeks of rearing (monsoon phase) and improved there after (1.06-1.27) with gradual improvement in water quality (post-monsoon) in both T_1 and T_2.

Table 9. Impact of phased harvesting on growth performance and yield of fish and prawn

Species stocked	Initial MBW(g)	Per Day Increment, PDI (g)			Yield (t) from refuge	AFCR
		120 DAS	120-165 DAS	165-210 DAS		
C. catla	3.7	0.52	$2.8^{438.4}$	$4.33^{54.6}$	1.042 (0.734)	1.77 (2.24)
L. rohita	3.0	0.30	$1.3^{333.3}$	$2.36^{81.5}$	0.760 (0.678)	
C. mrigala	4.8	0.33	$2.24^{578.7}$	$2.88^{28.5}$	0.802 (0.797)	
C. carpio	4.0	0.45	$2.62^{482.2}$	$3.65^{39.3}$	0.604 (0.595)	
M. rosenbergii	1.2	0.23	0.52^{126}	$0.57^{0.1}$	0.275 (0.247)	
			Total	Biomass =	3.48 (3.05)	

** Figures in parenthesis represent results of rice-fish culture without phased harvesting. Figures in superscript indicate percentage increase over previous PDI. AFCR, apparent feed conversion ratio.*

Table 10. Size heterogeneity and weight distribution (%) of *M. rosenbergii* at different days of rearing under high- density culture in deepwater rice-fish system

Days after stocking (DAS)	Weight distribution (%)					
	<20g	20-40g	40-60g	60-80g	>80g	MBW (g)
First cull, 120 DAS	61 (62)	39 (38)	— —	— —	— —	28.8 (27.3)
Second cull, 165 DAS	30.0 (42)	33 (33.3)	34 (24.7)	3.0 (—)	— —	52.2 (43.5)
Harvesting, 210 DAS	7.3 (23.7)	16.2 (31.4)	28.5 (33.9)	35.5 (11)	12.5 (—)	78.2 (53.0)

* *Figures in parenthesis represent results of rice-fish culture without phased harvesting.*

In both T_1 and T_2, bottom feeders (*C.carpio* and *C. mrigala*) registered better growth rate than that of *L. rohita* (column feeder) probably due to its superior feed utilizing capability and high degree of tolerance to fluctuation of DO and TSS concentration. Among bottom feeders, growth performance of *C. carpio* appears to be much better than *C. mrigala* in both T_1 and T_2. Faster growth rate of *C. catla* (surface feeder), *C. carpio* and *C. mrigala* (bottom feeder) were attributed to effective utilization of ecological niches and rich detrital food web that was maintained through periodic manuring, liming and fertilization.

Comparative slow growth and lower survival rate in T_2 was probably due to the fact that, under crowded condition, fish suffers stress due to aggressive feeding interaction and eat less resulting in a retardation of growth (Zonneveld and Fadholi, 1991 and Bjoernsson, 1994) and low survival (Procarione et. al., 1999). Significantly higher yield ($p < 0.05$) and species- wise faster individual growth performance ($p < 0.05$) in T_1 than T_2 was probably due to periodic phased harvesting that minimized the competition for food and space among the cultured species.

3.7.3 Size heterogeneity and weight distribution of *M. rosenbergii*

Interesting trend in the growth performance of *Macrobrachium rosenbergii* was noticed when grown together with fish in deep water rice-fish system. Faster growth was recorded in T_1 than T_2 probably due to periodic harvesting after 120 days of rearing (Table 8). Significantly higher mean body weight ($p<0.05$) was recorded (Table 10) at 165 and 210 days of rearing. At 120 days after stocking (DAS) 61% population was below 20g mean body weight (MBW) in T_1, which reduced significantly to 7.3% at 210 DAS. While in T_2, 62% population was below 20g MBW, which reduced only to 23.7% at 210 DAS. Similarly at 210 DAS, 12.5% population attained > 80g MBW in T_1 while none reached the target of 80g MBW by 210 DAS in T_2 (Table 10). This reduction in growth in T_2 (rice-fish culture without phased harvesting) was probably due to the competition for food, space and physiological stress at higher density, which agrees to the findings of Mohanty (2004).

3.7.4 Population structure and morphotypic existence of *M. rosenbergii*

Among various intrinsic and extrinsic factors associated with the culture of scampi, heterogeneous individual growth (HIG) happens to be a serious threat to the farmers resulting in heavy economic loss. *M. rosenbergii* is known to exhibit a complex social organizational hierarchy comprising morphologically distinct dominant, sub dominant and subordinate groups. The predominance of a definite social hierarchy among the male morphotype increases the differential growth pattern within these prawns. The males show high degree of HIG while the size distribution of the female population is rather homogeneous (Tidwell et.al.,2003). Usually, three male morphotypes (SM-stunted male, OCM- orange clawed male and BCM- blue clawed male) represent three developmental stages of the male maturation process and are known to undergo transformation from SM >> OC >> BC. SMs are subordinate, not territorial and initial stage of the developmental pathway. OCMs are sub dominant, represents high somatic growth. BCMs represent the terminal stage in the morphotypic transformation pathway. Once a set of prawn reaches the terminal morphotype stage, it inhibits the transformation of other morphotypes to successive stages. This leads to wide range variation in growth pattern. However, in this experiment, 210 days after stocking (DAS), existence of stunted male (Runt), orange clawed male, blue clawed male (Bull), virgin female and berried female in T_1 was 7.3%, 39%, 36%, 14.7% and 3% respectively (Table 11) while it was 23.7%, 27.3%, 11%, 13.5% and 24.5% respectively in T_2. In T_1, periodic removal of berried female however, helped in morphotypic transformation and male maturation process.

Table 11. Population structure and morphotypic existence (%) of *M. rosenbergii* in deepwater rice-fish system

Morphotypes	Days After Stocking (DAS)		
	120	165	210
Stunted Male (Runt) $^{\text{Subordinate}}$	34 (30)	22.6 (26)	7.3 (23.7)
Orange Clawed Male $^{\text{Subdominant}}$	22 (24)	30.9 (26)	39 (27.3)
Blue Clawed Male (Bull) $^{\text{Dominate}}$	—(—)	2.5 (—)	36 (11)
Virgin Female	44 (46)	31 (41.7)	14.7 (13.5)
Berried Female	—(—)	13 (6.3)	3 (24.5)

* *Figures in parenthesis represent results of rice-fish culture without phased harvesting.*

Periodic removal of blue clawed male (Bull) also minimized the Runt population to 7.3% at 210 DAS, which was 22.6% at 165 DAS. In pond/refuges, generally, 50% of the male population comprises the SM having the weight range of 5-20 g, while OCM (40%) and BCM (10%) are characterized by a wide weight range of 30-180g and 180-250g respectively. To overcome there relative proportion of SM, OCM and BCM morphotypes in the harvested population, following suggestions may be considered.

- Adopt two-stage (nursery and grow-out) rearing management
- Stock post larvae ($PL_{15\text{-}20}$) in nursery for 50-60 days till they attain 4-5 g size
- Sex segregation should be done at nursery site and only males should be stocked in rice-fish system (all male culture)
- Cull harvesting should be carried out from 2nd month onwards (BCMs should be targeted first followed by OCMs) in grow-out phase.

3.7.5 Food and feeding habit of fish and prawn in rice-fish system

Phytoplankton and zooplankton were most preferred food item for *C.catla* and *L.rohita*, while mud and detritus were highly preferred by *C.mirgala*, *C.carpio* and *M.rosenbergii* in rice fish integration system (Table 12). However, quantity-wise most consumed food items were artificial supplemental feed of rice barn and groundnut oil cake. Among bottom dwellers (*C.mrigala*, *C.carpio* and *M.rosenbergii*), phytoplankton and benthos were preferred more by *M.rosenbergii* while zooplankton and detritus by *C.carpio* and *C.mrigala*, respectively. Among bottom feeders, growth performance of *C.Carpio* appeared to be much better than *C.mrigala* probably due to their superior feed utilizing capability (Sinha, 1998). Omnivorous feeding behaviour was observed in case of each species except *Catla catla*, while the degree of omnivorous feeding behaviour was high in case of *M. rosenbergii* which agrees to the findings of Lee et al., (1980). Estimated degree of station (index of gutfulness) at fingerling stage was high in case of *Cyprinus carpio* followed by *Catla catla, Labeo rohita, Cirrhinus mrigala* and *M. rosenbergii*. While, high degree of satiation index was observed for *Cyprinus carpio* and lowest in case of *Catla catla* at advanced fingerlings stage (Table 14). Comparative degree of satiation, indicated a distinct declining trend form fingerling stage to advanced fingerling stage in case of each species. This was probably due to relatively low nutritional value of the ingested matter (mud and debris) and comparatively less preference to artificial feed at the initial stage of rearing that lend support to the findings of Spataru (1976). The intestine index x ($I.I = L_1 / SL$; where L_1 = Length of intestine and SL = standard length of fish) values of all analyzed fish varied from 6.7 to 9.8 and no correlation was found with standard

Table 12. Average % of individual gut content volume (abundance) and % of analyzed species in which mentioned food components were found (frequency) in deepwater rice-fish system

Food component	Abundance (%)					Frequency (%)				
	1	2	3	4	5	1	2	3	4	5
Supplemental feed	61.7^{+}	49.3^{+}	56.7^{+}	46.1^{+}	45.8^{+}	77.8	77.8	72.2	88.8	83.3
Phytoplankton	4.3^{-}	5.1^{-}	11.2^{-}	2.7^{-}	2.3^{-}	72.2	83.3	94.4	66.6	55.6
Zooplankton	1.6^{-}	4.3^{-}	5.9^{-}	1.9^{-}	1.4^{-}	44.4	83.3	88.8	72.2	44.4
Detritus+Mud	21.0^{-}	15.4^{-}	5.6^{-}	32.1^{+}	29.1^{+}	77.8	22.2	11.1	88.9	94.4
Benthos	16.4^{-}	1.0^{-}	-	12.2^{-}	12.2^{-}	61.1	5.5	-	55.6	44.5

1 - *M.rosenbergii*, 2 - *L.rohita*, 3 - *C.catla*, 4 -*C.carpio*, 5 -*C.mrigala*; $^{+}$ more than; $^{-}$ less than

length. These higher values of intestine index are typical to planktivorous, detritivorous and phytobenthophagous fishes.

Positive indices of electivity were observed for phytoplankton in monsoon-winter, while it was negative for zooplankton during the same period. Negative indices of electivity for zooplankton (-0.16 to -0.44) in case of all species were recorded during monsoon-winter (August-November) and improved thereafter. This was probably due to rich detrital food web in the initial phase of rearing where raw cattle dung was applied @ 5000 kg ha^{-1} for refuge preparation prior to stocking. However, positive indices of electivity for zooplankton were observed during December, only in case of *C. catla, L.rohita* and *C. carpio*. Similarly positive indices of electivity (0.07 – 0.38) for phytoplankton was observed in case of all species during August-October (monsoon) while it was negative thereafter probably due to increased density of zooplankton. Matrix of dietary overlap(s) of cultured species under deepwater rice-fish integration system (Table 13) revealed that degree of food preference was more similar between *C. carpio* and *M. rosenbergii* (0.9), while it was poorly overlapped between *C. catla* and *M. rosenbergii* (0.42). This high similarity index between bottom dwellers established a stronger possibility of competition for food among each other. However, there is a need to study closely the habit of fish movement from rice field to refuge and vice versa to relate natural food availability and feeding preference of cultured species.

3.7.6 Effect of fish and prawn on the growth and yield of rice

When the rice field is stocked with fish, the nitrogen, phosphorous, and potassium (NPK) contents of the soil and water increases significantly (Oehme et.al.,2007). Fish movements in the shallow water break the surface membrane formed by the microorganisms covering the soil. This increases the dissolved oxygen level in the soil and elevates its oxidation and reduction potential during the period of rice growth. These changes improve the oxygen content and effectively increase the utilization rate of soil nutrients. Fish in the rice-fish system promote more efficient use and distribution of NPK, thus reduce loss of fertilizer and increase soil fertility.

The increased dry weight of the whole rice plant, NPK content of the leaves and culm of rice plants, surface area of the leaves, chlorophyll content of rice plants at every developmental stages and strong activity of the root system that absorb more nutrient

Table 13. Matrix of dietary overlap(s) of fingerling to advanced fingerling stage of fish and prawn in deepwater rice-fish system

Species	*C.catla*	*L.rohita*	*C. mrigala*	*C.carpio*	*M.rosenbergii*
C.catla	-	0.7	0.52	0.52	0.42
L.rohita	-	-	0.56	0.52	0.45
C. mrigala	-	-	-	0.85	0.83
C.carpio	-	-	-	-	0.9
M.rosenbergii	-	-	-	-	-

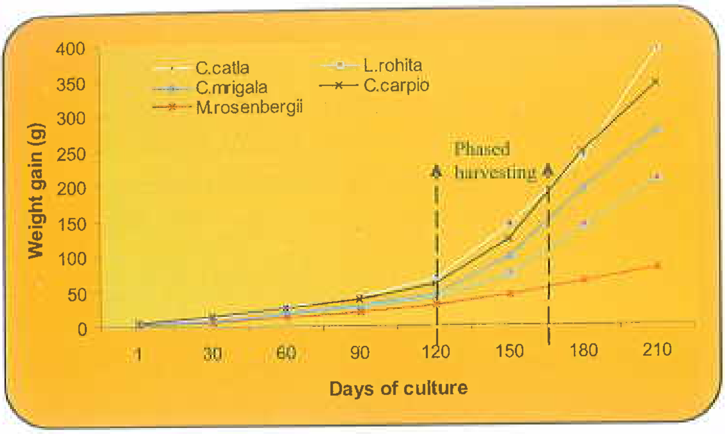


Fig. 11 Impact of phased harvesting on growth performance of cultured species in deep water rice-fish system

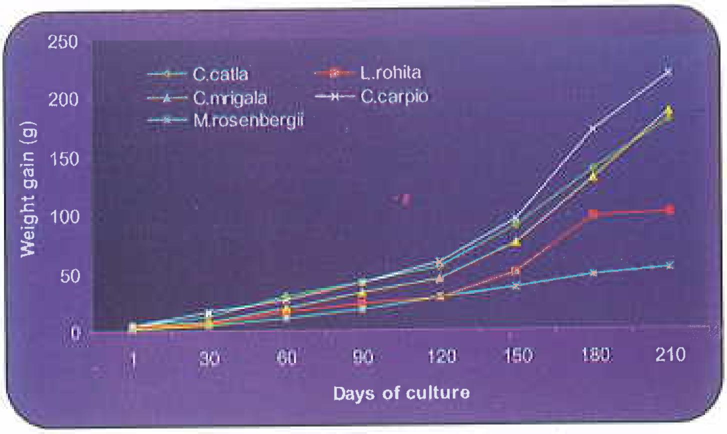


Fig. 12 Growth performance of cultured species in deep water rice-fish system without phased harvesting

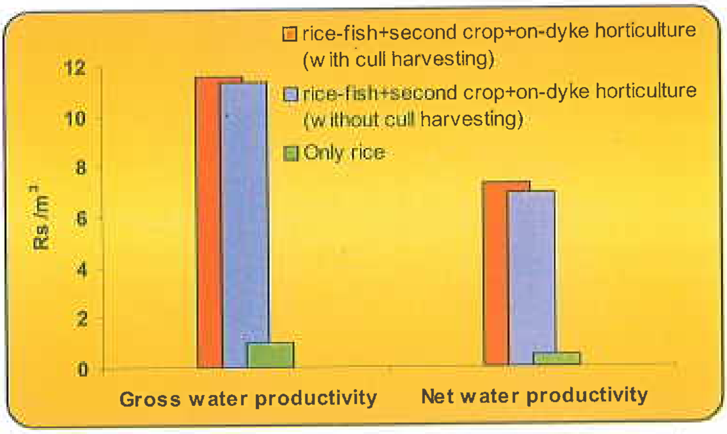


Fig. 13 Impact of phased harvesting on water productivity in deep water rice-fish system

Selective harvesting of common carp

Harvested fish from the rice field refuge

View of deepwater rice

Harvested prawn from the rice field refuge

Rice field refuge after harvest of rice

View of on-dyke horticulture

Coconut plantation on dyke

from the soil are usually recorded in the rice-fish system. The larger surface area of the leaves and the higher content of chlorophyll increase the efficiency of photosynthesis (Yang et.al., 2006), which would lead to the accumulation of more carbohydrates and therefore increase the number of effective ears, the number of grains per ear, and the weight of the grains. Increased dry weight of the whole rice plant is a fundamental condition for an increase in rice production.

In this deepwater rice-fish experiment, rice yield irrespective of treatments, was not more than 3.25 t ha^{-1} in presence of fish and 2.6 t ha^{-1} in mono-crop, probably due to higher water levels that decreased the number of panicles/m^2 and rice yield. Vromant et.

Table 14. Estimated degree of satiation (F_i) of fish and prawn in deepwater rice-fish system

Species	F_i			
	Fingerling stage in RF-I	Advanced fingerling stage in RF-II	Fingerling stage in RF-I	Advanced fingerling stage in RF-II
C.catla	5.9 ± 0.5	2.7 ± 0.4	5.4 ± 0.6	3.1 ± 0.4
L.rohita	5.1 ± 0.3	4.1 ± 0.5	5.1 ± 0.5	4.1 ± 0.6
C. mrigala	4.7 ± 0.3	4.2 ± 0.3	4.9 ± 0.5	4.4 ± 0.4
C.carpio	6.2 ± 0.5	5.3 ± 0.4	6.6 ± 0.4	5.7 ± 0.5
M.rosenbergii	5.2 ± 0.4	4.7 ± 0.1	5.6 ± 0.3	4.9 ± 0.1

RF-I: rice-fish without phased harvesting, RF-II: rice-fish with phased harvesting, F_i *= w X 100/W; where, w- weight of gut content and w- weight of individual fish/ prawn.*

al., (2002) also reported that the increased water levels lowered the rice yield at a rate of 0.06 t ha^{-1} cm^{-1}. However, this high water level has a positive impact on fish growth and survival though decreases the rice yield. Bottom feeder fishe mainly common carp, in known to bring minerals and organic matter from the sediment into suspension through its feeding activity. This results in increased water turbidity and particulate inorganic mater (PIOM), in the rice field, P release from the sediment and establish contact between the benthic and pelagic compartments which are otherwise fully separated. Moreover, fish stimulate the growth of phytoplankton and increased chlorophyll-a concentration (Frei and Becker, 2005) in rice field, which compete with rice for nutrient and energy, resulting in reduced rice yield as in the case of T_2.

3.7.7 Production intensification approach

The strategy for rice cultivation under rice-fish system, is low planting density (20-30% lower than the density used in regular fields), a small population and less fertilizer application. This helps in better root zone development, increasing number of tillers and improving ecological conditions (ventilation and illumination) that prevent lodging and help produce heavier grains, high and stable yields. The criteria of selection of fish species for stocking into rice-fish farming system should be based on the ability of fish species to filter and feed on plankton (bacteria, phytoplankton, and zooplankton) and to tolerate low levels of dissolved oxygen. An optimal stocking density of fish/prawn species is critical in attaining high cumulative fish yields and in reaching the upper carrying capacity of the system.

3.8 System's rice equivalent yield (REY) and water productivity

Considering the sale price of rice @ Rs. 5.00 kg^{-1}, fish fingerling @ Rs. 2.50 per piece, prawn @ Rs. 120.00 kg^{-1} and marketable fish @ Rs. 50.00 kg^{-1}, the rice equivalent yield (REY) was calculated. The highest REY (Table 7) was recorded in T_4 (58.0) followed by T_1 (38.5), T_2 (35.5) and T_3 (2.6). However, the OV-CC ratio indicates higher value (1.56) in rice-fish culture when phased harvesting was practiced (Table 15). Considering the

Table 15. Ratio of the output value (OV) to the cost of cultivation (CC) of the integrated farming system (average of three experimental years)

Treatment	Output Value (Rs. ha^{-1})	Cultivation Cost(Rs. ha^{-1})	Net return (Rs. ha^{-1})	OV-CC ratio
Deep water rice mono crop	13,000	10,900	2,100	1.19
Rice-fish (no phased harvesting) +A +B	1,93,095	1,43,098	49,997	1.35
Rice-fish with phased harvesting +A +B	2,08,220	1,33,685	74,535	1.56
Only fish & prawn culture with out phased harvesting +B	2,97,090	2,24,780	72,310	1.32

* A: low duty second crop (black gram, *Phaseolus mungo*); B: on-dyke horticulture; 1 USD=41 INR

Table 16. Comparative economic indices of water productivity of 1.0 ha unit area of deepwater rice-fish system

Treatment		Consumptive water use index (Rs./m^3)	
		GWP	NWP
T_1	Rice-fish (with cull harvesting) + 2nd crop (black gram) + on-dyke horticulture	12.52	7.30
T_2	Rice-fish (without cull harvesting) + 2nd crop (black gram) + on-dyke horticulture	11.32	6.9
T_3	Only deepwater rice	0.96	0.46
T_4	Only fish & prawn culture (without cull harvesting)	16.83	8.17

GWP: Gross water productivity , NWP: Net water productivity, 1 USD = 41 INR

selling price of additional produce from on-dyke horticulture and low duty second crop such as banana, papaya, brinjal, ladies finger and black gram @ Rs. 50.00 per bunch, Rs, 4.00 kg $^{-1}$, Rs. 5.00 kg^{-1}, Rs. 7.00 kg^{-1} and Rs. 15.00 kg^{-1} respectively, the net return from different treatments were calculated to compute the water productivity (Fig 13). The economic indices of gross water productivity was however, Rs. 12.52 /m^3, Rs. 11.32/m^3, Rs. 0.96 /m^3 and Rs. 16.83/m^3 for T_1, T_2, T_3 and T_4 respectively (Table 16). In rice-fish culture, enhanced gross (Rs. 12.52/m^3) and net (Rs. 7.30/m^3) water productivity was recorded when phased harvesting was practiced (T_1). This was probably due to enhanced growth rate, yield of fish and periodic income through sell of harvested fingerlings.

3.9 System's economic evaluation and impact of rice-fish culture

Rice-fish culture has the potential to enhance the net return per unit area, as fish have a high market value as compared to rice. Further, rice-fish culture makes multiple use of the rice field to maximize the utilization of land and water resources and can increase the production value of rice fields. In the present experiment, net return from rice-fish culture ranged between Rs. 49,997 ha^{-1} (T_2) - Rs. 74,535 ha^{-1} (T_1) which was 23-35 fold more than T_3 (Table 15). Moreover in rice-fish culture when phased harvesting is practiced the net return enhanced further by 49%. This infers that, initial high stocking density, followed by phased harvesting; in rice-fish culture is more beneficial, than traditional rice-fish farming.

Ways to intensify fish production from integrated rice-fish farming system involve management strategies like high-density rearing (stocking with a higher initial fish biomass) followed by phased/selective harvesting, when the growth curve of stocked fish/prawn starts to slow down. The productivity of the current practices of rice-fish farming has a great potential for improvement with further integration with duck and nitrogen-fixing aquatic fern azolla. Azolla can be utilized not only as organic fertilizer for crops but also as feed for livestock and fish. Fish, azolla and ducks integrated with a rice farming system can result in nutrient enhancement, pest (weed, insect, golden apple snail) control, feed supplementation and biological control. Nutrient recycling in an integrated rice-fish-azolla-duck farming system is better and more efficient compared to a rice-duck or rice-fish farming system resulting in higher productivity.

Fish and duck raised together with rice have their own economic value resulting in increased overall productivity of the farm. Rice-duck farming integrated with fish and azolla increases the production potential of this traditional farming practice. Natural resources management in tropical wetland rice fields through integrated production systems is a promising approach to introducing sustainability in rice farming and addressing ecological issues pertaining to the conservation of rice field ecology and aquatic bio diversity.

Economic, Social and Ecological Efficiency

Rice-fish culture makes multiple use of the rice field to maximize the utilization of land and water resources and can also increase the production value of rice fields. The economic efficiency is increased because the fish have a high value. In rice-fish culture, harmful insects and pests are greatly reduced. Therefore, pesticide application can be reduced or eliminated, and toxicity accumulation is minimized. This is beneficial to human health and the ecological balance of the environment. When fish are introduced into rice field ecosystem, change in the population and composition of aquatic organisms, and relationships among them takes place. Rice-fish culture can change the direction of energy flow in the ecosystem. In the rice field the stocked fish transform stagnant energy (e.g., weeds) and possibly lost energy (e.g., phytoplankton, zooplankton, and aquatic insects) into useable products (fish and rice). Rice-fish culture coordinates the interrelationship between the biotic and abiotic environments and reduces infectious diseases of livestock and humans. In rice fields, mosquito larval, maggots, snails, and leeches, which are the intermediate host of malaria, encephalitis, dysentery, blood fluke and filaria, reproduce rapidly. Fish particularly common carp and other omnivorous fish, consume and eradicate these pathogenic parasites and minimize the infestation rate of human beings, thereby creating an improved living standard and a better level of health for the farmers (Brahmanand *et al.*, 2006). In rice fields without fish, farmers must carry out regular and labour-intensive weeding. As a result, there is a heavy loss of soil fertility, solar energy and an increase of production cost. In some places, farmers do not plough the field when rice-fish culture is practiced. This further reduces the inputs needed for rice planting and therefore reduces production cost and increases the economic efficiency of rice cultivation.

Economic Impact

According to published report, in Bangladesh, the net return from rice-fish was over 50% greater than that from rice monoculture. In China, the increase varied from 45 to 270%. Growing fish was almost three times more profitable than rice alone. Rice yields in rice-fish culture were 8-26% higher, labour input 19-22% lower, and material costs were 7% lower (savings in the cost of controlling diseases and pests). Additionally, fish production increased the net income. Indonesian figures show that having two crops of rice-fish and using the rice field for a short intermediate crop or *penyelang* of fish has a 116% higher return than having two crops of rice and leaving the rice field fallow for two months or so. It is concluded that the rice-fish system is a profitable technology and that its adoption is likely to increase farm household income, labour absorption, and better liquidity (Purba,1998). In the Philippines, rice-fish farms yielded a 27% higher net return with fish compared to a single crop of rice (Sevilleja, 1992). In addition, it has been demonstrated that it is possible to achieve a three-fold increase in profitability of rice farming by culturing fish as well as rice (Israel et.al., 1994). However, Thailand, in contrast to previously mentioned countries, showed lower net returns in the rice-fish fields than in the rice-only fields. The Thai figures indicates that profitability in the rice-fish fields was only 80% that of rice monoculture due to the high initial investment in rice-fish culture. While in Vietnam, the net returns from the rice fields with unfed shrimps was 52% higher than that of rice monoculture and 176% higher in the rice fields where shrimps were fed with rice bran and decomposing animals.

Except for Indonesia, all the other countries consistently showed an increase in the overall labour requirement when fish are raised in the rice field, with the amount of increase varying from only 10% to as high as 234%. This was mainly due to the need to prepare the rice field for fish stocking as well as for fish harvesting. However, in some specific activities connected with the rice crop such as fertilizing, weeding and pesticide applications, the presence of fish actually lessened the labour required. Again the amount varies from activity to activity and from one area to another. In terms of fertilizer expense Bangladesh, Indonesia and the Philippines showed from 4% to 14% lower fertilizer costs in rice-fish fields, while the costs of chemical pesticides in rice-fish farms was significantly lower (44-86%).

Impact on Income

The immediate beneficiaries of the production of fish and rice yield in rice-fish farming are the farmers who adopt the technology. Although it seems obvious, the existence of such a relationship has not been demonstrated unequivocally. However, the fact that many farmers in different countries continue to practice it year after year, even without any government program, would seen to be proof enough of the benefits derived from this type of rice farming. Models developed using linear programming technique on a 2.3 ha farm in Philippines, show that the adoption of rice-fish farming technology can generate an additional 23% more farm income by raising fish as well in 0.5 ha. This increases to 91% if the entire 2.3 ha area is stocked with fish, even if rice production remains constant and farm requirements for cash and labour increased by 22% and 17% respectively (Ahmed et al., 1992).

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

Impact on nutrition

One benefit that is often assumed, but never supported by solid evidence is that farmers who culture fish in their rice fields have improved nutrition. In the case of rice-fish farming there are no figures available as to how much the caloric and protein intake or the per capita fish consumption of farmer families have been increased by the availability of fish once these are grown in their own rice fields. Income augmentation was the most frequent reason provided for engaging in rice-fish, additional food only ranked next. In Bangladesh it was pointed out that extra income was the most appreciated benefit from growing fish (70%) followed by increased food for the family (59%).

Improvements of a farming household's nutrition as a result of culturing fish in the rice fields may just be an incidental and perhaps even indirect effect, such as being able to buy meat or chicken as a result of the extra cash earned from fish. The main benefit of rice-fish farming is often seen as providing an opportunity to earn cash. Improvement in the local community's nutrition has been cited as one of the benefits of rice-fish farming. With greater availability of fish, the local population of a rice farming community will have easy access to fish at affordable prices. However, in a free market the farmer may opt to sell the fish to a trader at a higher price than what the neighbors can afford. The trader in turn may opt to bring the fish to the nearest urban center where prices are higher. This is a common situation in most fishing communities where fish can be difficult to find in the local market having been siphoned off to the cities.

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

Impact on Public Health

Mosquitoes are known carriers of malaria and dengue fever. Certain species of freshwater snails serve as hosts to trematodes (*Schistosoma* spp.) that cause schistosomiasis when it enter the human bloodstream. Fish in rice fields very well controls these two public health vectors. A third aspect is that rice-fish culture may reduce the use of agricultural chemicals that pose a health hazard to humans. Field surveys in China indicate that mosquito larvae densities in rice fields with fish were only 12 000 .ha^{-1} as against 36 000 .ha^{-1} in rice field without fish (Wang and Ni, 1995).

In Indonesia, fish were found to be even more effective in controlling mosquitoes than DDT. After five years of fish culture in rice fields, malaria cases decreased from 16.5% to 0.2% in a highly endemic area for malaria. In countries such as China, black carp (*Mylopharyngodon piceus*) is used to control snails that are intermediate hosts in parasite transmission. In Katanga, the majority of snails in rice fields were controlled by *Haplochromis mellandi* and *Tilapia melanopleura* stocked at 200 fish.ha^{-1} and 300 fish.ha^{-1} respectively. Hence its concluded that well maintained aquaculture operations contribute, often significantly, to the control of insects and snails of agricultural and medical importance, and that integrated management programs should be pursued to keep vectors and pests at levels where they do not cause significant problems. Fish are potentially a good biological herbicide and insecticide and stocking can greatly reduce, if not completely eliminate, the need for using chemical pesticides. The presence of fish discourages farmer from applying pesticides. The reduction or elimination of the need to apply chemicals cannot but result in an environment that is safer and healthier for the people.

Social impact

When there is a large-scale adoption of rice-fish integration involving an entire community, the social impact can be quite profound. The use of fallow rice lands for fish culture by landless farmers in Indonesia is one such case. The situation prevailing in Indonesia in the past was that landless tenants were allowed to use the rice fields for fish culture during the fallow season (*palawija* system). Nowadays, the use of the rice fields for fish production during the fallow season is not limited to landless tenants, but involves fish breeders requiring a larger area for raising fingerlings (Fagi et.al., 1992). Although the Indonesian example may be unique, in general adoption of rice-fish farming should result in job creation. Physical modifications of rice fields to accommodate and harvest fish require extra labour. In the Philippines ancillary activities connects to tilapia fingerlings production in rice fields are: diking and excavation, making hapa-nets, harvesting seines and other fish culture accessories, renting out water pumps, harvesting nets, oxygen tanks, repair of pumps, harvesting, sorting and packing of fingerlings and transport of fingerlings. Each type of activity is done by a different person, thus creating job opportunity.

Impact on the Environment and Biodiversity

The impact of rice farming on the environment, including its contribution to the greenhouse effect, should be a matter of concern to everyone. There is no doubt that the development of rice lands has resulted in the loss of natural wetlands and marshlands, although this made a difference between widespread famine and food sufficiency in many parts of the world. A rice field is known to be the habitat of a diverse assemblage of species. Intensification of rice cultivation with an associated increase in chemical pesticide use is reducing the biodiversity. Since rice-fish farming often reduces the need to use chemicals for pest control, this assists in enhancing the population structure and preserving a diverse rice field biota. The main species include rice, fish, weeds, plankton, photosynthetic bacteria, aquatic insect, benthos, rice pests, water mice, water snakes, birds, soil and aquatic bacteria. Utilizing the existing native species for rice-fish culture serves to actively preserve the biodiversity.

Impact on Water Resources

Freshwater is a limited resource and the integration of fish with rice is one way of using water more efficiently by producing both aquatic animal and rice. With fish in the rice field, a greater water depth has to be maintained and more water may be required, an issue raised half a century ago. Even without fish, rice farming consumes large volumes of water.

For rice culture in general, crop needs a minimum of 1 000 to 1 800mm of water (Sevilleja et.al., 1992). If a hectare of rice field produces 10 mt of rice, it still takes from 1 to 1.5 m^3 of water to produce 1 kg of paddy. Fish, a non-consumptive user of water and while they can degrade the water they do not use it up. If cleaned, the same water can be returned and reused by the fish. The increased water use is due to percolation and seepage (P&S) and leakage (L), which increase with rice-fish culture due to the deeper water maintained, a purely physical process that takes place with or without the fish. It is estimated that the average water requirement for rice culture is 1 662 mm while rice-fish culture require up to 2 100 mm, or 26% more than rice monoculture. The main water losses are attributable to P&S (67%), followed by L (21%). Thorough puddling during land preparation, good maintenance of the dikes and proper sealing of inlets and outlets may reduce the water losses.

Impact on Sustainability

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

3.10 Global importance in terms of food production, environmental issues and climate change

Rice-fish farming systems are of great importance in providing food and animal protein for subsistence farmers living in ecologically-fragile regions. Meanwhile, fish can improve the diet composition of farmers by increasing the supply of animal protein.

Numbers of studies have demonstrated that, in comparison with monoculture rice farming fields, the rice-fish systems either have a higher production of rice or a higher production of fish.

The rice-fish system is conducive to the recovery of soil fertility (Mohanty, 2003a) and the prevention of soil degradation, which is a global environmental issue. Being low external input system, the rice-fish farming system necessitate only small amount of pesticide and fertilizer. The application of pesticide can be lowered to 50% of that of modern, high-input rice production; sometimes, no pesticide application is required. An experiment of rice-fish integration for 3 years in the same plot showed that, with rice-fish integrated farming, there was an increase of 27.9, 44.3. 6.5 and 28.2% in total nitrogen, total phosphorus, total potassium and organic matter, respectively, in the soil (Zheng and Deng, 1998). Similarly, another long-term study for a period of 10 years showed the nitrogen fixation role of the system increased the content of organic matter, total nitrogen and total phosphorus in the soil by 15.6-38.5, when rice-fish farming was adopted (Lu and Li, 2006).

Global climate change is closely linked to agricultural production (Frei et.al., 2007). At present, the average content of CH_4 in the atmosphere has increased to 1.8 ml m^{-3}. The greenhouse effect caused by CH_4 is 20-60 times worse than that caused by CO_2. Therefore, FAO has listed CH_4 as one of the most important micro air pollutants. A total of 10-20%

of CH_4 in the atmosphere comes from rice fields. Research has shown that the rice-fish system is capable of lowering the emission of the greenhouse gas CH_4. Huang et al., (2001) previously quoted research of 3 years also proves that the emission of CH_4 from a sole rice field is 4.73 mg m^{-2} ha^{-1}, whereas that from the rice-fish system is 1.71 mg m^{-2} ha^{-1}, which is a dramatic drop. Recently, it has been estimated that the emission of CH_4 from the rice-fish system is 34.6% less than that from mono-culture rice fields (Lu and Li, 2006).

4.0 CONCLUSIONS

Rice-fish system in India is in urgent need of dynamic conservation. A full recognition of its multi-ecological functions must be achieved, such as its role in preserving biological diversity, protecting food security, enriching roil and lowering the emission of green house gases. In light of the present situation of India's rice-fish farming, basic research on rice-fish eco-systems should be emphasized, including research on the baric techniques of rice-fish farming, integrated techniques and the technology required for engineering components/intervention.

In rainfed lowland/ waterlogged areas, *in-situ* conservation of rainwater, short-duration aquaculture with rice, integration of horticulture on the embankment and utilization of conserved water for growing low duty *rabi* crop seems to be a viable solution for increasing the income of small and marginal farmers. This eco-friendly dual production system (rice and fish) in *kharif* and on-dyke horticulture helps in generating additional income, employment opportunity and nutritional security. Moreover, income can further be enhanced if high-density initial stocking followed by phased havening of fish/prawn is practiced in rice-fish culture.

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