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Development of Rice-Fish Farming in Enhancing Economic and Seasonal Benefits: A Case Study from Bangladesh

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Abstract

Integrated rice-fish farming can enhance the efficiency of land use, diversify production with varied foods, and support smallholder income security. However, pathways to adoption, economic viability, and seasonal advantages related to integrated rice-fish farming need more documentation in northwest Bangladesh. To fill this knowledge gap, this exploratory study investigated the process of adoption, farm attributes, comparative productivity, and seasonal livelihood benefits of integrated rice-fish farming among selected farmers in the Dinajpur Sadar subdistrict. This study analyzed the data collected from 30 rice-fish farms that also had rice-only fields, making comparison possible between rice-fish and rice-only agriculture. Several participatory rural appraisal techniques, such as historical timeline analysis, transects, focus group discussion, and questionnaire survey, were used to collect the data. The majority of rice-fish farmers were young and educated farmers practicing in medium lowland irrigated rice farming systems. Commonly cultured fish species were carps and Tilapia, stocked at a density of 24,700 ± 3250 individual ha^{-1}. While rice production did not vary significantly between rice-fish and rice-only field practices, additional fish production raised gross income, net income, and benefit-cost ratio. Gross income in rice-fish farming was Bangladesh Taka BDT 506,632 (≈USD 6247.00) and BDT 212,600 (≈USD 2621.45) in rice-only practice, whereas net income was BDT 373,243 (≈USD 4602.25) and BDT 126,667 (≈USD 1561.86), respectively.

Keywords: Bangladesh; rice-fish; economic and seasonal benefits; farming community; polyculture

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1. Introduction

Bangladesh, one of the most densely populated countries in the world [1], is characterized by its diverse biological resources, having a favorable delta for agro-ecological conditions [2,3]. Agriculture is the dominant sector in this farming country, with significant contributions to the economy (13.42% of the gross domestic product [GDP]) [4]. According to BBS (2025) [4], 44.67%, 17.37%, and 37.96% of the total labor force are employed in the agriculture, industry, and service sectors, respectively, highlighting the importance of agriculture as a major source of rural employment.

Due to rapid urbanization, extreme flood and drought events, as well as the conversion of agricultural lands for non-agricultural activities, the amount of land available for food production is decreasing [2,5]. Optimizing production with limited resources to meet the growing nutritional demands of millions of people, along with improving environmental sustainability, is a significant challenge for agricultural operations [6–8]. There is no scope to expand the cultivable lands, therefore, intensification of agricultural practices is the only solution for increasing farm production to maintain the socio-economy of farming communities in Bangladesh [9]. This intensification, using inorganic fertilizers and chemicals, has had negative effects on climate change, land use, the fertility of farming lands, and consequentially, on human health from consuming agricultural products [10,11]. Furthermore, the rice farming practiced in Bangladesh is mainly fed from underground water [11], which does not ensure the optimum carrying capacity of lands and proper water utilization [12].

Bangladeshi people of the Bengal fertile land have been relying on fish for nutrition (60% of animal protein source) [13] and rice for an affordable source of energy (70% of calorific intake) [14,15] for centuries. The national diet is fish with rice, leading the nation to be described as *Maache-Bhate Bangali* (meaning "a Bengali is made of fish and rice") [16,17]. Traditionally, rice fields have offered wild fish, such as small indigenous fishes to harvest, as they inhabit the shallow paddy fields for reproduction [18,19], especially in and around the monsoon. This supplementary harvest from rice fields often provides a good package of nutrition for small, marginal households in rural areas [18,20]. Unfortunately, a number of ecological and anthropogenic factors, including land degradation, over exploitation, pollution, and agricultural intensification have reduced wild fish populations in rice fields.

Integrated rice-fish farming has been adopted for producing rice and fish simultaneously, ensuring the utilization of natural resources on a complementary basis [18,21–24]. The fish benefit from living in a shaded habitat in the shallow warm water [22] of the rice field, which is abundant with diverse food, such as microbes, insect larvae, periphytons, benthic snails, and plankton [21,25–27]. The uptake of nutrients from fish feces by plants, the inherent pest control by fish, and plant growth triggered by the movements of fish, makes the stocking of fish complementary for paddy fields [21,27]. This rice-fish integration also reduces the use of agrochemicals in rice production via the beneficial support from fish feces, while the fish get a natural food web facility from the plankton growth. This mutual relationship increases productivity, environmental sustainability, harvest intensity, product diversification, and household nutrition [18].

Although integrated rice-fish farming has considerable potentials to enhance agricultural productivity, farm income, and resource-use efficiently, its adoption in Bangladesh remains low [19–21]. In a development project implemented across various regions of Bangladesh, WorldFish trained farmers in rice–fish farming, but only 36% of the trained farmers subsequently adopted the practice [11]. Existing literature of Bangladesh has shed light on constraints to adoption, livelihood benefits, production efficiency, and rice field-based fish seed production; nevertheless, much lesser emphasis was made on the development pattern of rice-fish farming, temporal pattern of benefit realization, and financial comparison between rice-fish and rice cultivation from the same farming households. This implies that there is still a knowledge gap as far as the economic feasibility of rice-fish farming as well as its role in ensuring continuous seasonal income, food security, and farm diversification among other things are concerned. Thus, in order to contribute toward addressing these gaps, this study was designed for achieving the following objectives: (i) to identify the development pattern and diffusion process of rice-fish farming in Dinajpur Sadar area of northwestern Bangladesh; (ii) to identify socio-economic and farm characteristics of rice-fish farmers; (iii) to compare costs, returns, net income, and benefit-cost ratio

of rice-fish and rice-only farming plots; and (iv) to identify livelihood benefits derived from multiple fish harvests.

2. Materials and Methods

2.1. Site Selection

Dinajpur Sadar (25°14′–25°38′ N and 88°05′–88°28′ E), a sub-district of northwest Bangladesh under the Dinajpur District of Rangpur Division was selected for data collection (Figure 1), based on the high adoption of integrated rice-fish farming [20]. Although famous for rice production, aquaculture in this area remains marginal, leaving great potential for the integration of fish farming with rice cultivation to meet the nutritional demands of poor and marginal households [21].

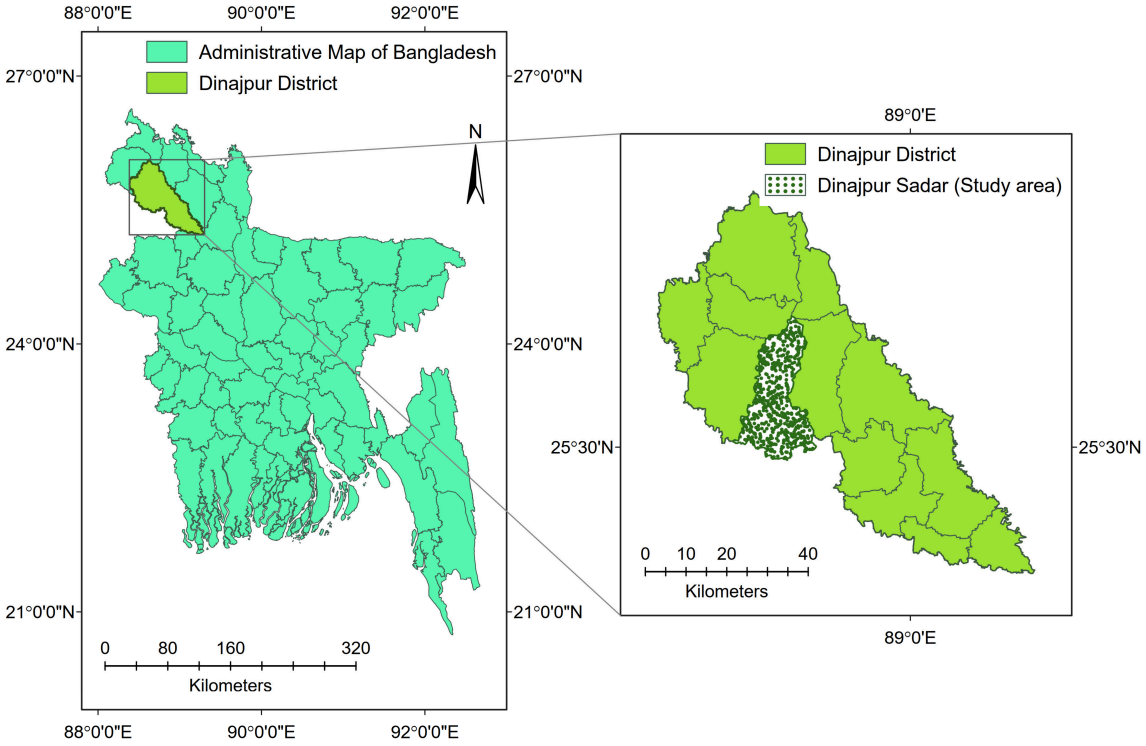


Figure 1. Map of study area in the Dinajpur district of Bangladesh, prepared using ArcGIS Desktop version 10.8 (Esri, Redlands, CA, USA).

2.2. Data Collection

This research was conducted by applying mixed methodology involving participatory rural appraisal (PRA) techniques and a structured questionnaire survey. PRA techniques were applied for understanding the development aspects of the process, its spatiality, the nature of the land-use system involved, and the seasonality of the practices, while the questionnaire survey was used for collecting household- and farm-level data on inputs, production cost, and income.

The transformation process that occurred due to the introduction of fish cultivation in rice fields in Dinajpur Sadar was analyzed through historical analysis of events using a participatory tool that is frequently used in community planning and rural development research [28]. This analysis included identification of various factors that influenced the transition from traditional rice cultivation to rice-fish cultivation in the area under consideration. Exploratory case studies were used since first rice-fish farming operations are carried out only by few farmers in the chosen areas, and second it was necessary for the purpose of gathering more data on farm management practices and other costs associated

with their operation on as seasonal basis at household level rather than providing a national estimation of such an activity. Prior to conducting the household survey, a list of 65 rice-fish farmers was generated based on information received from local rice-fish farmers, community contacts, and general information about rice-fish farms in the Dinajpur Sadar area. The transect walk served the purpose of knowing the location of the rice-fish farm, rice-only farm, pond, ditch, irrigation pump, and households themselves.

A farmer was considered eligible for inclusion in the final sampling if he or she satisfied the following criteria: (i) practiced rice-fish farming in Dinajpur Sadar district; (ii) also cultivated rice-only fields for comparison purposes between rice-fish and rice monocultures under similar circumstances in terms of family and local environment; (iii) had direct control over farm-management activities such as fertilizer, feed, and seed inputs, as well as cultivation, irrigation, harvesting, and marketing activities; (iv) had access to reliable information about farm operations in terms of activities, cost, yield, and family income; and (v) agreed to take part in the survey and answer questions regarding farm operations.

Of the list of 65 rice-fish farmers validated through above criteria with the help of local rice-fish farmers and researchers own observations, 30 farmers who practiced rice-fish culture and rice-only cultivation were selected for structured questionnaire survey. Due to the limited number of eligible farmers and need for farmers to have rice-fish and rice-only plots, the process used a criterion sampling method where farmers were picked from the list when the number exceeded the necessary respondents for a particular community. This study can be described as an exploratory case study since there are specific inclusion criteria for participation. Inclusion criteria provided the opportunity for the investigation to compare households' rice-fish and rice-only farming methods, although findings cannot be generalized.

To understand the physical features, natural resources, and land use patterns of the study area, focus group discussions and transect walks were conducted with the assistance of the representative of local rice-fish farmers. The transect walk was done in rice-fish farming villages to understand the topographic distribution of farming households, rice-fish plots, rice-only farming plots, ponds, ditches, and irrigation facilities. This cross-sectional observation also facilitated the verification of the information given by participating farmers. Six focus group discussion sessions were conducted in one village (Raniganj) to synthesize the historical timeline of rice-fish farming development in the area. The historical timeline was further supported by a review of relevant literature. During the focus group discussion, information on seasonal farming activities and benefits was collected.

Following the transect walk and focus group discussion, a structured questionnaire was designed for collecting data at the household and farm level. This questionnaire was prepared according to the research objectives, information collected through participatory approaches, and review of the existing literature on the subject matter. The following categories were included in this questionnaire. (i) Household demographic and socio-economic profile; (ii) Ownership of land, ponds, and rice field; (iii) Rice-fish plot profile such as size of plot, size of ditch, ditch depth, water source, and ecosystem type; (iv) Fish species, stocking density, stocking time, harvesting method, and purpose of the fish (for household consumption or sales); (v) Rice cultivation practices in *Boro* and *Aman* seasons; (vi) Input cost like tillage, rice seeds, fertilizers, irrigation, insecticides, herbicides, labor charges, and fish seed; (vii) Rice and fish yield, income, net profit, and benefit-cost ratio; and (viii) Seasonal activities, consumption, and monetary benefits.

The questionnaire was initially designed in English and later translated into and applied using Bangla to enable the farmers to comprehend and answer all questions in the questionnaire. Before the actual administration of the survey questionnaire, the draft

questionnaire was tested with key informants from the locality, as well as certain selected farmers in the study area, who were not part of the final sample of farmers. The pre-testing helped in determining whether all questions were comprehensible, locally applicable, and were able to capture all the required data concerning production costs and seasonal factors. This involved the rephrasing of some questions, dropping others that were redundant and including locally applicable terminology used by the farmers in their farming activities and seasonal cycles.

A structured and pre-tested questionnaire was used to collect quality survey data. The first author, who was an MSc student in 2016, received training from her research supervisors and conducted a pilot survey to identify and resolve any ambiguous questions. The questionnaire included clear questions, skip logic, and consistency checks to minimize missing or erroneous data. During the fieldwork, she reviewed each completed questionnaire for missing or inconsistent responses, while the supervisors periodically accompanied her and randomly re-checked selected interviews for quality assurance. Face to face interviews were also conducted with 30 rice-fish farmers by the first author, with each interview taking approximately one hour. The interview covered household and socioeconomic characteristics, farm and land characteristics, rice-fish and rice farming practices, seasonal activities, inputs, cost of production, income and household level benefits. The information obtained from the interviews was triangulated with the findings from focus group discussions, transects and informal consultations. Before the interviews, the research objectives were clearly explained to participants in Bangla. Participation was clearly voluntary, the respondents were informed that they could decline to answer any question or withdraw from the interview or discussion at any time. Informed verbal consent was obtained from all participants before data collection. The farmers were also told that the information would be kept anonymous in publishing the findings. To minimize recall bias, data were collected close to the production period, and respondents were asked to report costs and production based on specific farming activities. Complex expenditures were recorded separately by input category to improve the accuracy of reporting. As rice cultivation was the farmers' primary occupation, they were familiar with their production practices and associated costs and were therefore able to provide detailed information based on their farming experience.

As the study involved 30 farmers in selected rice-fish farming communities in Dinajpur Sadar, the conclusions were made as evidence from an exploratory case study rather than statistically generalizable to all rice-fish farmers in Bangladesh. Nevertheless, the inclusion of households practicing both rice-fish but also rice-only farming provided a valuable basis for within-household comparison.

2.3. Data Analysis

Data were entered into MS Excel and subjected to error checking (such as range check, duplicate entry, double data entry verification) before analysis. MS Excel was used to code data, generate tables and graphs, while the coded survey data were analyzed using SPSS (Version 23.0, IBM, Armonk, NY, USA) for descriptive and inferential statistics. A simple tabular cost-benefit analysis was conducted to compare rice-fish and only rice farming systems. Since both systems were operated by same farming households, the comparisons were made at farming-system level, and paired sample *t*-test was used to examine differences in input use, output, expenditure, revenue, net profit and benefit-cost ratio. The statistical results were interpreted as exploratory comparative evidence, and p-value of <0.05 was considered statistically significant.

3. Results

3.1. Socio-Economic and Farming Characteristics of Rice-Fish Households

A limitation of the study is the small sample size (N = 30) nevertheless, the key findings are reported as percentages, supported by the corresponding frequencies presented in Table 1. The socio-economic findings (Table 1) show that young farmers constituted the largest age group among surveyed rice-fish farmers, with 50% of respondents aged 21–40 years. Middle-aged farmers aged 41–55 years accounted for 26.67%, while older farmers aged 56–60 years represented 23.33% of the respondents. The main occupation of the majority of farmers was traditional agriculture (63.3%), while a few had business (16.7%), teaching (10%), student (3.3%), union parishad secretary (3.3%) and government service (3.3%) backgrounds. The average household size (including males and females) was large (7.68), but the number of earners was less (1.86), with the economic contribution of households dominated by male members. Most of the rice-fish farmers were educated and a significant portion (26.67%) had university degrees.

Table 1. Socio-economic and farming characteristics of rice-fish farmers in the study area in Dinajpur, Bangladesh.

Socio-Economic Characteristics	Frequency	Percentage	Mean ± SD
Age (years)			
21–40 (Young age)	15	50.00	
41–55 (Middle age)	8	26.67	
56–60 (Old age)	7	23.33	
Main occupation			
Agriculture farmer	19	63.30	
Business	5	16.70	
Teacher	3	10.00	
Student	1	3.30	
Union Parishad Secretary	1	3.30	
Government Service	1	3.30	
Household size			
No of males			3.89 ± 1.50
No of females			3.79 ± 1.29
No of earners			1.86 ± 1.01
Education			
Primary level	3	10.00	
Secondary level	10	33.33	
Higher secondary level	9	30.00	
University degree	8	26.67	
Land ownership			
Own land	27	90.00	
Leased in	2	6.66	
Multi-ownership	1	3.33	
Pond ownership			
Own pond	19	63.33	
Leased in	1	3.33	
Shared in	1	3.33	
Multi-ownership	2	6.66	
No pond	7	23.33	
Cultured species in rice fields			
Carps	15	50.00	
Tilapia and Carps	8	26.66	
Tilapia	3	10.00	
Carps, Tilapia, and Pangasius	2	6.66	
Carps, Tilapia, Shing, and Magur	2	6.66	

Table 1. *Cont.*

Socio-Economic Characteristics	Frequency	Percentage	Mean ± SD
Stocking density (fish per hectare)			
19,760–22,230	4	13.33%	
22,230–24,700	5	16.67%	
24,700–27,170	14	46.67%	
27,170+	7	23.33%	

Note: Percentages were calculated based on the total number of surveyed farmers, N = 30. Blank cells indicate that the values were not applicable for that variable.

The majority (90%) of farmers had their own land for rice-fish farming. Mixed results were found for pond ownership and species selection for culture with rice (Table 1). Approximately 63% of rice-fish farmers had their own pond, followed by multi-ownership (7%), shared-in (3%), and leased-in ponds (3%). Of the rice-fish farmers, 76.67% practiced traditional pond-based fish farming in the study area. In terms of species combinations in rice-fish farming, tilapia (*Oreochromis niloticus*) was the most common fish, cultured either as a single species or in combination with other species. Carps, including catla (*Catla catla*), ruhu (*Labeo rohita*), silver carp (*Hypophthalmichthys molitrix*), common carp (*Cyprinus carpio*), etc. were the top preference of farmers. Approximately 50% of respondents cultured carps in their rice fields. Eight farmers cultured tilapia (*O. niloticus*) with carps, three farmed only tilapia, two farmed carps, tilapia (*O. niloticus*) and Pangasius (*Pangasionodon hypophthalmus*), and two farmed carps, tilapia (*O. niloticus*), Shing, (*Heteropneustes fossilis*), and Magur (*Clarias batrachus*) with rice. Commonly, 46.67% of the total farmers interviewed followed a stocking density of 24,700–27,170 fish/ha and 23.33% farmers were found to stock at a relatively high densely (27,170+).

3.2. Rice Field Ecosystems and Plot Characteristics

The transect walk identified three topographical gradients: upland rice ecosystems, medium lowland irrigated rice ecosystems, and lowland rain-fed rice ecosystems (Figure 2). Rice-fish farming has been developed in the medium lowland ecosystem. According to the survey data, the average rice-fish farming plot size were 0.36 ± 0.27 ha ranging from 0.38 to 0.48 ha. The average ditch size was 0.07 ± 0.04 ha (range: 0.02–0.24 ha), while the average ditch depth of rice-fish plot was 1.26 ± 0.16 m, ranging from 0.91 to 1.52 m.

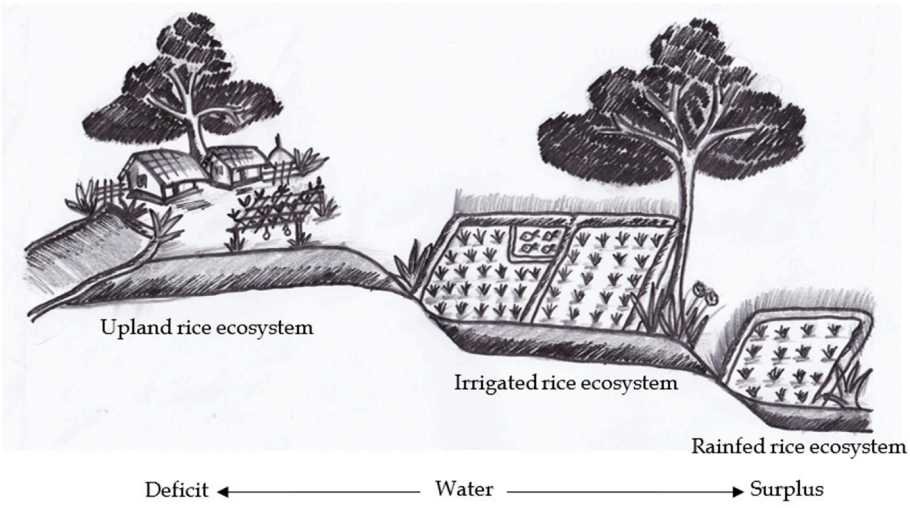


Figure 2. Rice field ecosystem characteristics in the study area in Dinajpur, Bangladesh.

3.3. Seasonal Benefits of Rice-Fish Farming

In Bangladesh, the rice-fish system is a year-round cultivation, of predominantly two rice (*Boro* and *Aman*) varieties, with a concurrent or rotational presence of fish. The cultivation periods of *Boro* and *Aman* are January to June and July to December, respectively (Table 2). Plots are prepared by applying fertilizer, then the irrigation and planting of *Boro* seedlings are done at the beginning of the year (January to February). When the inorganic fertilizer action produces food organisms, farmers stock the first batch of fish in late March, followed by a second batch at the beginning of April. In these months, supplementary fertilizer is provided to increase the production of fish food. After investing in labor and inputs for the last four months, farmers start to get benefits by harvesting fish for consumption in May. The returns come in monetary form from June in a continuous process, while they harvest *Boro* and fish in late June or in the first half of July. From June farmers harvest and stock fish in the rice field in a partial manner, and cash inflow continues until December from fish production. By this time, a continuous fish harvest ensures the nutritional security of farming households in later months. Following the same rice cultivation practice for *Aman*, farmers get a rice-based second financial return between late November and the beginning of December. This time, farmers store rice for selling later at a high price. In addition, surplus fish remaining in the rice fields facilitate and/or further extends the rice-fish farming systems for the following year, which in turn contributes a large amount of fish for household consumption.

Table 2. Seasonal activities and benefits of rice-fish farming.

Months	Activities
January	• Plot preparation for transplanting *Boro* † rice • Applying first dose of inorganic fertilizer, lime, and cow dung to improve soil fertility of rice field • Transplantation of seedlings of *Boro* rice
February	• Transplantation of seedlings of *Boro* rice • Irrigating rice fields when necessary • Second dose of fertilizer in rice field
March	• Weeding the rice fields • Irrigating rice fields when necessary • Stocking fish seed (first round) • Applying supplementary fertilizer to produce natural food organisms for the stocked fish
April	• Stocking fish seed (second round) • Irrigating rice fields when necessary • Applying supplementary fertilizer to produce natural food organisms for the stocked fish
May	• Irrigating rice fields when necessary • Applying supplementary fertilizer to produce natural food organisms for the stocked fish • Harvesting fish for household consumption
June	• Harvesting *Boro* rice • Partial harvesting and selling of fish • Partial restocking of fish seed
July	• Partial harvesting of fish and selling, and partial restock of fish seed • Harvesting fish for household consumption • Applying first dose of inorganic fertilizer, lime, and cow dung to improve soil fertility of rice field • Transplantation of rice seedlings of *Aman* ‡
August	• Transplantation of rice seedlings of *Aman* • Irrigation of rice fields • Second dose of inorganic fertilizer in rice field

Table 2. *Cont.*

Months	Activities
September	• Applying second dose of fertilizer in rice fields • Weeding the rice fields • Irrigating rice fields when necessary • Applying supplementary fertilizers to produce natural feed organisms for stocked fish
October	• Irrigating rice fields when necessary • Applying supplementary fertilizer to produce natural food organisms for the stocked fish • Partial harvesting of fish and sell, and partial restock of fish seed • Harvesting fish for household consumption
November	• Partial harvesting and selling fish • Harvesting fish for household consumption • Harvesting *Aman* rice
December	• Partial harvesting of fish • Harvesting fish for household consumption • Harvesting *Aman* rice • Harvesting fish for household consumption

† *Boro:* dry season irrigated rice; ‡ *Aman*: wet season rain-fed rice.

3.4. Comparative Financial Analysis

The results show that rice–fish farming was economically more profitable than rice-only farming in both *Boro* and *Aman* seasons (Table 3). Rice production did not differ significantly between the two systems in either season ($p > 0.05$), indicating that fish integration did not reduce rice yield. However, fertilizer inputs and pesticide costs differed significantly between the systems. Fertilizer application was generally higher in rice–fish plots during the *Boro* season, whereas comparatively lower amounts were required during the *Aman* season. Rice–fish farming also involved additional costs for fish seed (BDT 24,700 ha^{-1}) and feed (BDT 21,990 ha^{-1}). Despite these additional costs, the integration of fish generated an average fish production of 2932 kg ha^{-1}, contributing approximately BDT 293,200 ha^{-1} in additional revenue. Consequently, the combined gross revenue from *Boro*, *Aman*, and fish was BDT 506,632 ha^{-1} under rice–fish farming, compared with BDT 212,600 ha^{-1} under rice-only farming. The rice–fish system generated a substantially higher net profit (BDT 373,243 ha^{-1}) than the rice-only system (BDT 126,667 ha^{-1}), with BCRs of 3.80 and 2.47, demonstrating the strong economic contribution of fish integration.

Table 3. Comparative financial analysis between rice-fish and rice-only farming on per hectare basis in northwest Bangladesh.

Input/Output Items Rice Production	*Boro*			*Aman*		
	Rice-Fish (1)	Rice-Only (2)	*p* Value *	Rice-Fish (3)	Rice-Only (4)	*p* Value *
(A) Cost items						
(a) Tillage and plot preparation cost (BDT ha^{-1})	2670 ± 434	2560 ± 155	0.353	2317 ± 319	2440 ± 223	0.115
(b) Rice seed: *Boro* and *Aman*, respectively@ BDT 90 kg^{-1} and 55 kg^{-1}	4092 ± 754	4006 ± 171	0.557	1483 ± 378	1516 ± 105	0.513
(c) Cost of fish seed: 24,700 ± 3250 fry/ha @ BDT 1/fry	24,700 ± 3250					
(d) Cost of fish feed (BDT ha^{-1})	21,990 ± 2374					
(e) Inorganic fertilizer						
Amount of urea (kg ha^{-1})	144 ± 33	128 ± 8	0.007	65 ± 29	102 ± 6	0.001
Cost of urea (BDT 17 kg^{-1})	2463 ± 577	2048 ± 124	0.001	1039 ± 465	1638 ± 99	0.001

Table 3. *Cont.*

Input/Output Items Rice Production	*Boro*			*Aman*		
	Rice-Fish (1)	**Rice-Only (2)**	***p* Value ***	**Rice-Fish (3)**	**Rice-Only (4)**	***p* Value ***
Amount of TSP (kg ha^{-1})	115 ± 17	128 ± 7	0.001	59 ± 19	76 ± 5	0.001
Cost of TSP@ BDT 21 kg^{-1}	2428 ± 374	2688 ± 163	0.246	1244 ± 418	1689 ± 102	0.001
Amount of MP (kg ha^{-1})	108 ± 22	115 ± 7	0.038	54 ± 17	76 ± 5	0.001
Cost of MP@ BDT 17 kg^{-1}	1836 ± 395	1958.40 ± 119	0.107	929 ± 296	1305 ± 79	0.001
Amount of zinc and gypsum for *Boro* (kg ha^{-1})	63 ± 20	76 ± 4	0.003	9 ± 3		
Cost of zinc and gypsum@ BDT 66 kg^{-1}	1935 ± 1183	2336 ± 142	0.073	559 ± 44		
(f) Pesticide and herbicide cost (BDT ha^{-1})	2417 ± 209	2620 ± 2276	0.001	1969 ± 137	2491 ± 1678	0.101
(g) Irrigation cost (BDT ha^{-1})	24,500 ± 3750	22,342 ± 2873	0.010	5600 ± 1435	4500 ± 1321	0.007
(h) Total labor cost (BDT ha^{-1})	14,828 ± 9714	12,900 ± 3656	0.304	14,390 ± 3834	16,896 ± 1028	0.002
Gross cost (a–h)	103,859	53,458		29,530	32,475	
(i) Gross cost of *Boro* and *Aman* in rice-fish (BDT ha^{-1})	133,389 (1+3)	85,933 (2+4)				
(B) Return						
Rice production (kg ha^{-1})	7219 ± 1240	7186 ± 436	0.884	2911 ± 1210	3072 ± 187	0.396
Value of rice@ BDT 18,750 MT^{-1}	135,364	134,400		54,375	56,250	
Value of rice straw@ BDT 2590 MT^{-1}	12,244	11,384		11,449	10,566	
Gross revenue from rice cultivation	147,608	145,784		65,824	66,816	
Gross revenue from *Boro* and *Aman* rice (BDT ha^{-1})	213,432	212,600				
Fish production (kg ha^{-1})	2932.07 ± 1731.20					
Revenue from fish@ BDT 100 Kg^{-1}	293,200					
Gross revenue (BDT ha^{-1}) from *Boro*, *Aman* and Fish	506,632	212,600				
(C) Economic Evaluation						
Net profit (BDT ha^{-1}): B − A	373,243	126,667				
Benefit-Cost Ratio (BCR) = B ÷ A	3.80	2.47				

* Results are presented as means ± standard deviations. Statistical significance was assessed using paired sample *t*-tests at 5% level of significance. In the study year (2017), USD 1.00 was equivalent to BDT 81.10.

3.5. Rice-Fish Dissemination Process

The group discussion and structured questionnaire survey identified that the integration of rice and fish was adopted in the early 1990s by farmers, as an integrated pest management tool to increase rice production and profit margins (Figure 3). However, only a few farmers were motivated by the different extension projects at that time. Later, participatory action and support from non-governmental organizations (NGOs) motivated more farmers to adopt this technology to ensure adequate household nutrition and the intensification of farming systems. About 20% of the farmers adopted rice-fish technology during 2000-2010 (Figure 3). After 2010, research advances in demonstrating the environmental sustainability of this practice promoted rice-fish farming. Sufficient power and the mechanization of farming, particularly modern irrigation and tillage technologies, have stimulated farmers to adopt the technology, optimizing the use of natural resources, with minimal environmental degradation.

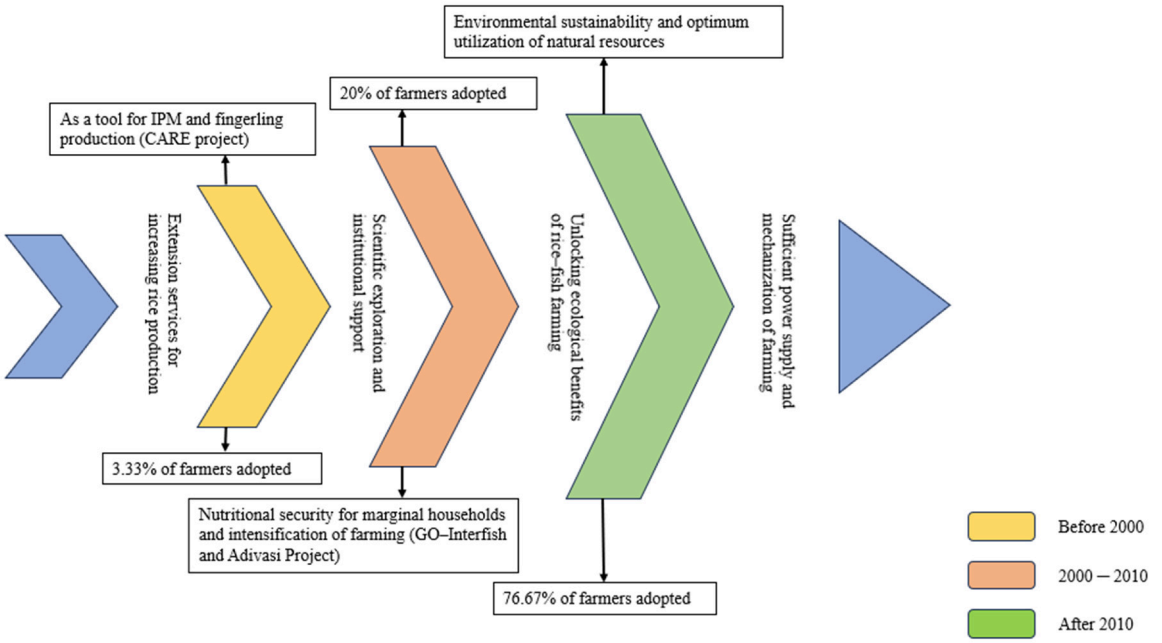


Figure 3. Historical timeline of adopting rice-fish farming in northwest Bangladesh, developed based on FGDs in Raniganj village but representing whole study area. IPM: Integrated pest management; CARE: Cooperative for Assistance and Relief Everywhere; GO-Interfish: Greater Opportunities for Integrated Rice-Fish Production Systems.

4. Discussion

This exploratory case study indicated that integrated rice-fish farming in Dinajpur Sadar involved some socio-economic, seasonal and economic gains to the particular households. As such, the observations made from the study suggested that the majority of the respondents adopting the practice were young farmers, the majority of whom had formal education, and most of them had secure land for practicing rice-fish farming. The rice-fish farming was conducted in a medium lowland irrigated rice ecosystem characterized by suitable field topography since the practice required adequate water retention capacity, presence of irrigation facilities, and provision of ditching for fish farming. The carp and tilapia had been identified as the most popular fish species used alone or together for rice-fish farming. The financial analysis revealed that rice-fish farming was financially more profitable than conventional rice-only farming. Although rice yield did not differ significantly between the two systems, the additional fish production increased gross cost, gross revenue, net profit, and benefit-cost ratio. Rice–fish farming requires additional labor for ditch construction, stocking, feeding, and partial harvesting which increase production costs to an extent. Gupta et al. (1998) [29] reported that the cost of rice–fish farming was only 15.4% higher than rice-only farming in the *Boro* season and 17.5% higher in the *Aman* season. However, partial harvesting of fish provided farmers with regular cash income while also contributing to household food consumption.

One of the main strengths of this study is that rice-fish and rice-only plots were compared within the same households. Within-household comparison helped us understand the economic difference between the two farming systems since the variation in farming capability, access to land, availability of labor, orientation toward markets, and agro-ecological environment at the household level got minimized in this context. The other strength of this study is the application of both participatory rural appraisals and semi-structured surveys that helped to compare the financial outcomes of rice-fish farming in combination with the development pathway, spatial pattern of land use, suitability of environment, and seasonal benefits of the households. Prior research works conducted on

Bangladesh's rice-fish farming have considered issues relating to production efficiency, food security, livelihood impacts, and obstacles to adoption of rice-fish farming [11,20,27,30]. This research work extends these issues by considering the adoption experience, farm-level economics, environmental suitability, and seasonal benefits of the communities.

The socio-economic status indicated that integrated rice-fish farming was used more often by young and educated farmers. Such finding may be explained by the more knowledge-based character of integrated rich-fish farming. Contrary to rice monoculture, rice-fish farming involves the consideration of different elements: rice cropping, water regulation, fish stocking, fish movement, dike maintenance, fertilization, avoiding pesticides, partial harvests, and proper marketing time. Young farmers might be more prone to adopting an integrated system because of their higher flexibility in decision making and openness to innovation in agriculture. Educated farmers might possess the skills to understand the complexities associated with fish cultivation in rice fields, communicate with agricultural extension agents, keep track of costs and productivity, and manage the farm according to seasonality. These interpretations are broadly consistent with technology adoption literature, which identifies age, education, risk assessment, and awareness of information as factors associated with agriculture technology adoption [31,32]. However, given the cross-sectional nature of this study, these findings indicate associations rather than causal relationships. Alternative explanations, such as differences in land acquisition or inheritance, farming involvement, access to resources, information, extension services, and market opportunities, cannot be excluded. Nevertheless, these findings are consistent with previous Bangladesh-specific studies on integrated rice-fish farming which show that integrated farming systems increase productivity and profitability [20,27,30], although the technical aspects require consideration.

Household composition also seemed to be a significant factor in the practice of adopting and managing the farming system of rice-fish. In this research, relatively larger households with few numbers of earners were noted as adopters. These observations imply that rice-fish farmers are likely to adopt as an option to increase family income while ensuring more food supply with equal land holdings. The role of family in the production of fish in the rice fields concurred with those studies by Sarma & Ali (2005) [33] and Pandey & Upadhayay (2012) [34] in terms of how household composition, family labor availability, and dependency burden can affect involvement in fish-based farming systems. Large households can offer free or inexpensive family labor which can be employed in the usual chores such as guarding the rice-fish plot areas, checking and managing the dikes, maintaining the water levels, applying additional inputs, partial harvesting of fish, and marketing the produce to the local markets. On the other hand, household with more dependent members tend to be highly motivated to engage in diversified farming activities as rice-fish farming offers both staple and animal-based food.

Ownership of the land turned out to be another significant variable influencing adoption. About 90% of the surveyed farmers conducted rich-fish cultivation on lands owned by themselves. It means that land security played an important role in making investments into land transformation, ditch digging, embankment reinforcement, water retention, and fish stocking. Moreover, farmers did not want to invest money in land modification and rice-fish adoption on rented lands since it might be very risky and farmers preferred not to distribute their investment among others. Indeed, rice-fish farming implies a modification of land where rice is cultivated through the creation of refuge ditches, reinforced embankments, and water management systems. Such actions might be unprofitable in case farmers did not have permanent and secured access to the land where such measures were supposed to be taken. The same factors were observed in Bangladesh as land access, water access, financial resource availability, technical assistance, and institutional support

affected the implementation of rice-fish farming [11,20,30]. Nonetheless, certain plasticity in using ponds is possible as well.

Species selection in the study area was determined through consideration of factors such as availability of seeds, farmer preferences, tolerance to the environment, rate of growth, and marketability of the species as well as compatibility with the shallow water environment in rice field settings. Based on the survey findings, carp and tilapia were identified as the dominant fish species in the study area. Carp are widely cultured and consumed in South Asia because of their diversity and complementary feeding niches. Different carp species occupy distinct ecological niches and utilize a broad range of natural food resources, plankton, detritus, benthos, plant materials and periphytic materials. These characteristics make carp particularly suitable for polyculture in rice fields. Tilapia was also extensively used due to its tolerance to varying water quality, fast growth, local market demands, and ready availability of seeds. In regard to species combinations, tilapia was the most preferred species when it came to raising fish in the rice paddies. The tilapia was raised alone or in combination with other species like carp, catfish, and other species of fish. This was because the fry of tilapia fish are easily obtained since tilapia reproduce rapidly in rice fields [12,18,35].

Decentralized fish seed availability could have been another factor contributing to the development of the rice-fish farm system in northwestern Bangladesh. Earlier studies pointed out how the use of rice fields for fish seed availability and dissemination at the farmer level played an instrumental role in this regard [21,36,37]. This study is in line with earlier research results, given that farmers adopted this technology using various species of tilapia and carp. Access to fish seeds and familiarity with their adoption were crucial factors influencing this phenomenon, especially in the context of rice-fish farms, where the timing of seed distribution needs to match that of rice fields with regards to water availability, rice growing period, and seasonal risk. In this situation, if there is no availability of seeds, farmers cannot adopt them at the right time when there is enough food available in the rice field. Hence, future efforts will need to ensure proper fish seed supply besides farmer training and proper field designs.

According to the historical timeline, the development of rice-fish cultivation in the Dinajpur Sadar region has been influenced by different types of research, extension work, NGO interventions, and farmer learning. Though rice-fish cultivation has been practiced in Bangladesh for a long time, the development of this practice in northwestern Bangladesh is significantly associated with extension programs and rice field fish seed production activities. In this connection, one may refer to the Northwest Fisheries Extension Project (NFEP), Cooperative for Assistance and Relief Everywhere (CARE) interventions, and subsequent activities conducted by NGOs to spread the technology among farmers [36,38]. The previous studies conducted in Bangladesh prove that rice-fish farming could improve food security and livelihood as well as enhance production efficiency, but their adoption was not uniform among different regions [11,20,27]. The current research sheds some light on why there is a difference between regions as it is proved that this agricultural technique was developed where all favorable factors came together. Having considered the need to optimize resource usage in combination with the changing environment, it becomes clear that the shift towards rice-fish cultivation becomes inevitable.

Transect walk found out that rice-fish farming practice existed primarily in the medium lowland irrigated rice ecosystem. Such a finding has an agronomic and aquacultural basis. In medium lowlands, there exists adequate water availability for fish rearing without the risk of flood associated with deeper lowland rain-fed ecosystem. On the other hand, upland ecosystems have little water depth for proper fish rearing. Lowland ecosystems had risks of flash flooding while uplands lacked adequate water, which explains why farmers shied

away from such sites. Thus, rice-fish farming depends on a particular site's suitability. Plot characteristics that were common in study area included rice-fish plot size, ditch size, ditch depth, and other characteristics were similar to rice-fish farming plots in the Mymensingh region [27]. From the findings above, scaling should focus on areas where adequate water depth, dikes, irrigation, soil quality, and flood risks exist.

This study revealed that fertilizer application was generally higher in rice–fish plots during the *Boro* season but comparatively lower during the *Aman* season. This seasonal difference may partly be attributed to the residual fertilizing effects of fish culture. Fish excreta, uneaten feed, and other organic wastes can add nutrients and organic matter to rice field ecosystems, thereby potentially reducing the requirement for inorganic fertilizers in the subsequent *Aman* season. Fish movement within the rice fields may also disturb the soil, enhance water circulation, and facilitate the release and redistribution of nutrients stored in the sediments. Furthermore, nutrients remaining in the soil following inorganic fertilizer application during the *Boro* season may persist and contribute to nutrient availability for the subsequent *Aman* crop, potentially further reducing fertilizer requirements in rice–fish plots. The study also found lower pesticide and herbicide use in rice–fish plots during the *Aman* season. Fish may consume insects, larvae, weeds, and other living organisms that compete with or adversely affect rice growth. Several previous studies have reported that rice-fish co-culture enhances ecological processes in rice field ecosystems, including nutrient cycling, insect pest suppression, weed removal, and biological interactions [20,23,39–41].

The issue of differences in the cultivation of *Boro* and *Aman* rice should be taken into account. While *Boro* rice is grown in irrigated circumstances, *Aman* rice cultivation is more reliant on rainfall. In the study region, tillage and irrigation requirements in the *Boro* season were higher than in the *Aman* season due to high power and water use needed for dry-season plowing. However, the advantage of moisture in the *Aman* season resulted in decreased requirements of tillage operation. Moreover, farmer used different varieties and transplanting density depending on season. High-yielding *Boro* varieties, like BR 28, were planted in denser planting conditions compared to taller *Aman* varieties, such as BR 34 and Sorno. This difference might have resulted in non-compliance with a decreasing pattern for fertilizers and other inputs use in rice-fish systems. This pattern has also been observed in integrated systems, when results depend on the management level, species combinations, and season [42,43].

Rice production did not differ significantly between rice-fish and rice-only plots in either the *Boro* or *Aman* season, indicating that fish integration did not reduce rice yield. However, the additional fish production significantly enhanced financial benefits of rice-fish system. Such results indicate that fish served as another enterprise in rice-fishing farming system rather than replacing rice production in rice fields. The improved benefit-cost ratio in the rice-fish system therefore reflected higher total system productivity and profitability, mainly due to fish production, rather than a significant increase in rice yield. These results support earlier studies that proved that rice-fish system helps increase the economic returns from farming, diversify production, and increase efficiency in use of natural resources [11,20,27,44]. Our results align with other studies from rice-fishing systems in Asia, where ecological compatibility helped increase the overall system productivity and minimize reliance on external inputs [22,40,41].

Seasonal aspect of rice-fish farming is especially significant in this regard. In case of rice-only system, most of income comes only at times of rice harvest and during other seasons there can be some shortage of money in the family budget. In case with rice-fish farming, money from the sale of fish could come periodically over several months. Harvesting fish before rice season for personal use would help households to overcome seasonal shortage of food while selling some extra fish for the market could bring some

cash during time of seasonal necessity for cash. One of the most applicable features of rice-fish farming as a livelihood practice is seasonal availability of money. It is also one of the reasons why rice-fish farming could be appealing to households with limited number of income earners. The same benefits of rice-fish farming have been described in Bangladesh [11,27,36].

The nutritional significance of partial harvesting of fish is also significant. Fish is an important animal source of proteins and micronutrients for Bangladesh, and the practice of rice-fish farming permits families to have fish harvested directly from their own farms. Partial harvesting can lead to an increase in number of times fish get consumed, particularly during those times when purchasing fish in markets may be challenging for poor families. While direct consumption was not measured in this current study, the trend in households' consumption of fish can indicate that rice-fish agriculture leads to diverse eating habits and animal-sourced foods consumption. The relevance of this aspect is that rice is an essential component of diets in Bangladesh, contributing significantly to the energy content of meals, while fish constitutes a significant proportion of animal-sourced foods eaten by families in the country [13–15,17]. As such, the role of rice-fish agriculture should be evaluated not just in terms of profitability but in the context of seasonal food access as well.

The adoption and scaling up of rice-fish farming need to be viewed within the context of institutional support. In Bangladesh, agricultural extension and fisheries extension have typically been separate institutions, and there could be issues with regard to coordination between the two when such a system is recommended. Farmers need guidance on choosing rice varieties, fish species, stocking density, water depth, restrictions on pesticide use, fertilizer application, harvesting method, health of fish, and marketing. Hence, rice-fish farming needs coordinated extension from both the agriculture and the fisheries sectors. Our current results confirm that while development projects and NGOs have contributed significantly to the scaling up process, more institutional support would be needed for scaling up the practice. This aligns with previous research that highlights how household characteristics, institutional support, availability of inputs, and extension services have affected the adoption and impact of integrated rice-fish systems [11,20,30,37].

There are certain limitations associated with the study. Firstly, since the study used a sample of only 30 rice-fish farmers of selected communities of Dinajpur Sadar, the findings cannot be generalized to all rice-fish farmers in Bangladesh. Secondly, some costs and production data were collected from memory, and thus may be subject to recall bias. In addition, certain opportunity costs, particularly those associated with family labor and land use, were not included because farmers used their own family labor and land for both rice–fish farming and rice-only farming. Thirdly, measurements of environmental performance indicators such as water quality, soil fertility, pesticide residue levels, biological diversity, and greenhouse gas emissions were not undertaken. Future studies should overcome these shortcomings by employing large-scale surveys at multiple locations, farm-level measurement of economic and environmental variables, and measuring dietary intakes to assess nutritional impacts.

5. Conclusions and Recommendations

Rice-fish farming is considered a valid method to cater to the growing need for alternative food sources and income generation among rural farmers of Bangladesh. The present study, an exploratory case study from Dinajpur Sadar, revealed that rice-fish farming enhanced the total profit for farmers primarily due to extra fish production, whereas there were no significant differences in the yield of rice when rice-fish and rice-only cultivation were compared. Based on this result, it is expected that integrated rice-fish

farming has the potential to enhance gross earnings, net profit, benefit-cost ratio, seasonal income, and availability of fish for the family.

This study has presented location-specific evidence on financial and seasonal advantages associated with integration of fish with rice from the standpoint of local farming households. Nevertheless, the results obtained in the study must be treated cautiously since this study was performed using data collected from only 30 farmers within the chosen communities of one sub-district. Hence, the results should not be generalized to the rice-fish farmers of all subdistricts of Bangladesh until more studies with samples drawn from different agro-ecological zones of Bangladesh are undertaken. The recommendations that arise from this exploratory case study are:

- At the national and local levels, there needs to be better coordination among the different stakeholders engaged in rice cultivation, aquaculture, and rural extension programs;
- Rice-fish farming operations need to be scaled up gradually and in a site-specific manner, taking into consideration the availability of favorable land type, soil and water retention, irrigation facilities, supply of fish seed, and low flood incidence;
- Interventions targeted at farmers should include training regarding rice-fish farm design, stocking density, species choice, water control, harvesting and marketing of produces; and
- Coordination between government ministries, research organizations, extension programs, NGOs, input (for example, resources, budget, and equipment) providers, and fish market actors, needs to be enhanced to facilitate farmers willing to engage in rice-fish farming.

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