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Note

Economic and environmental benefits of integrated paddy-cum-fish farming in the smallholder systems of Meghalaya, North-east India

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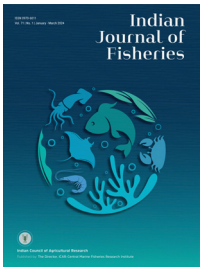

Abstract

The efficiency and sustainability of paddy-fish integrated farming were studied under the hill agro-climatic conditions of Meghalaya, North-east India. A five year study (2018-19 to 2022-23) was conducted in four blocks of Ri-Bhoi District, with 20 replicate plots of 0.1 ha each per block, covering a total study area of 8 ha. Traditional paddy monoculture was compared with an integrated system combining the improved rice variety RCM-10 with a composite culture of Amur carp (40%), Mrigal (30%), and Silver barb (30%) at a stocking density of 0.5 fish m^{-2} (5,000 fingerlings per ha). Fish growth was assessed monthly (n=30 per species per plot), and soil and water quality were monitored quarterly and weekly, respectively. The integrated system earned higher net returns than monoculture (`108,555 *vs* 44,220 ha^{-1}), but its benefit-cost ratio (BCR) was lower (1.61 *vs* 2.18) because fish seed and feed raised the cost of cultivation considerably. Mean fish production was 1,050 kg ha^{-1}, with a stocking-weighted survival of 73.7%. Rice yield under integration (3,465 kg ha^{-1}) was 23% lower than in monoculture (4,500 kg ha^{-1}), partly because the peripheral trench and sump reduced the cropped area by about 13%. Soil organic carbon increased by 23%, pest incidence decreased by 65%, and irrigation water productivity improved by 30%. The system has potential for upscaling in Meghalaya, provided farmers can meet the higher working capital requirements and the associated yield and labour trade-offs are addressed through appropriate extension support.

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Agricultural sustainability and food security remain two significant problems in North-east India, a concern that is particularly acute in Meghalaya, where traditional farming often fails to provide optimal returns owing to increasing environmental pressure (DoES, 2020). This challenge is all the more pressing because, according to Jaffrelot *et al*. (2024), India will need to produce about 350 million t of foodgrains by 2050 to meet the needs of its growing population. In Meghalaya, where agriculture is the backbone of the economy, small landholdings and limited access to mechanisation heighten the need for innovative approaches that boost productivity while maintaining ecological balance (DoA, 2006).

The urgency of this research is further underscored by Meghalaya's agricultural demographics. Jeeva *et al*. (2006) reported that as many as 83% of the state's population are directly dependent upon agriculture for their livelihoods. Yet only 48% of the total geographical area is considered suitable for cultivation, which places considerable strain on small and marginal farming families. Climate projections by Chakraborty *et al*. (2025) indicate concerning shifts in seasonal rainfall patterns, with decreased precipitation during critical growing periods and a greater frequency of extreme weather events, despite only modest changes in total rainfall (a 0.3-3% increase since the 1970s). Integrated paddy-fish farming offers a strategic response to these challenges. It enhances water-use efficiency and improves climate resilience. During dry spells, keeping water in the plots for fish survival also sustains irrigation for the rice crops, giving the system considerably improved water retention capacity overall.

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Evidence supporting integrated farming has been growing steadily across North-east India. Roy *et al*. (2024) recorded revenues up to 245% higher in Tripura than traditional farming. In a systematic overview, Das (2018) identified numerous benefits, such as increased organic soil (28%), improved water-use efficiency (35-40% decrease in consumption), and increased ecological resilience due to natural pest regulation functions. Corroborating these results in the same region, Debnath (2025), in a three-year comparative study across three districts of Tripura, found that paddy-fish integration increased paddy production by 14.3% and added an extra 350 kg ha^{-1} of fish, giving 69.5 to 107.2% better returns than rice monoculture. More recently, Samaddar *et al*. (2025) reported that these integrated systems have the potential to double farm revenue while also increasing biodiversity and reducing the use of chemical inputs.

Although such studies have been conducted in many regions of North-east India (Lipton, 1983; Goswami *et al*., 2004; Misra *et al*., 2014; Sharma *et al*., 2017; Das, 2018; Gogoi *et al*., 2022; Roy *et al*., 2024; Debnath, 2025), the specific agroecological environment of Meghalaya, including its mountainous topography, typical rainfall distribution, and sociocultural context, has remained comparatively unexamined. Addressing this gap is urgent, as climate variability and persistent market uncertainties continue to strain small scale farming in Meghalaya. Therefore, the present five year study was designed to fill this gap in knowledge through a careful assessment of the economic and environmental consequences of paddy-fish integration, with the intention of providing evidence based recommendations to policymakers, agricultural extension services, and farmers. It is expected that the findings will offer a viable framework for sustainable agricultural practices in other agroecological regions, within and beyond the region.

A five year study (2018-19 to 2022-23) was conducted in four blocks of Ri-Bhoi District, Meghalaya, following a randomised block design (RBD). The sites were Umling (25°43' N, 91°55' E), Umsning (25°45' N, 91°53' E), Bhoirymbong (25°40' N, 91°45' E), and Jirang (25°58' N, 91°42' E), which are representative of the average paddy growing areas in Meghalaya (Fig. 1). Each block contained 20 plots of 0.1 ha, of which 10 were managed under the integrated system and 10 under traditional monoculture, giving 40 plots per system and a total study area of 8 ha. The four administrative blocks served as the blocking (replication) factor of the RBD, and the two systems were allotted at random to plots within each block. Fish were stocked 15 days after transplanting and harvested along with the rice crop each year.

Field preparation started with the modification of the plots to accommodate fish for culture. A peripheral trench measuring 1 m in width and 0.5 m in depth was dug around each experimental plot. A harvest sump measuring 2 m x 2 m x 1 m was constructed at the lowest lying point of each plot. Water inlet and outlet structures of 0.4 m width were installed and provided with screens of 1 mm mesh size to prevent any chance of fish escape. The plot dikes were reinforced to a height of 0.6 m and a width of 0.5 m to maintain a minimum water depth of 15 cm throughout the cultivation period.

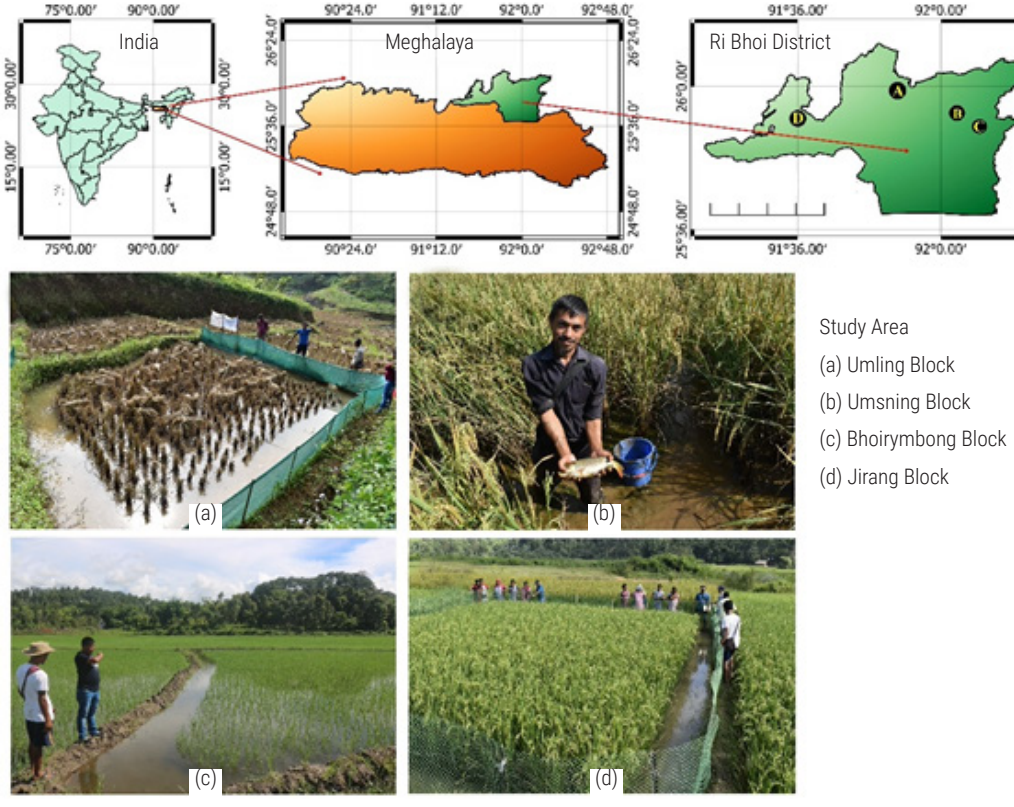

Fig. 1. Experimental plot layout for integrated paddy-cum-fish farming in Ri-Bhoi District, Meghalaya

The rice variety RCM-10, an improved high yielding line developed by the ICAR-Research Complex for NEH Region (duration 120-125 days), was transplanted at a spacing of 20 cm x 20 cm following standard agronomic practices (Mahapatra *et al*., 2012). Cattle manure was applied at a rate of 10 t ha^{-1} before transplanting. No chemical fertilisers or pesticides were used at any point during the entire experimental period. Fish fingerlings were stocked into the plots 15 days after rice transplantation at a stocking density of 0.5 fish m^{-2} (5,000 fingerlings per ha). Fish fingerlings were procured from the fisheries farm of ICAR-Research Complex for NEH Region, Umiam, Meghalaya. The species composition was: Amur carp (*Cyprinus carpio*) 40%, Mrigal (*Cirrhinus mrigala*) 30%, and Silver barb (*Barbonymus gonionotus*) 30%. The initial length and weight of the fingerlings at the time of stocking averaged 9.0±0.5 cm and 8.5±0.8 g, respectively. Supplementary fish feed consisting of rice bran and mustard oil cake in a 1:1 ratio, with a crude protein (CP) content of 24.5±2.8%, was provided daily at a rate of 2% of the total fish biomass. Water depth was maintained at 15–20 cm during the rice growth period and was increased to 30 cm within the peripheral trenches. Water quality parameters, including temperature, pH, and dissolved oxygen, were monitored weekly using portable water analysers (Lutron PDO-519, Taiwan; Eutech Instruments PCSTestr 35, Singapore). Soil samples were collected quarterly from a depth of 0-15 cm at five points in each plot, composited, air-dried, passed through a 2 mm sieve and analysed for soil organic carbon (SOC) by the wet oxidation method (Walkley and Black, 1934). Pest incidence was recorded fortnightly on 10 randomly selected hills per plot as the percentage of tillers showing dead hearts or white ears caused by stem borer. The percentage changes in SOC and pest incidence reported here were computed relative to the monoculture plots of the same block and year.

Data were collected on both rice and fish production parameters. Rice growth measurements included plant height, tiller number, and grain yield. Fish growth was monitored through monthly sampling of 30 individuals per species per plot, for which length and weight measurements were taken. At the time of harvest, the total fish biomass and survival rate were recorded. Weight gain was calculated as final weight minus initial weight, and feed conversion ratio (FCR) as the quantity of feed supplied divided by the fish weight gained. All economic data, including input costs and revenue streams at the prevailing market rates, were carefully documented throughout the cultivation period.

Irrigation water productivity (IWP) was calculated using the depth-volume method (Ali and Talukder, 2008). Water depth was measured daily at five fixed points within each plot using graduated stakes, and the total water volume was computed based on the plot area and water depth measurements. Surface runoff was estimated using collection drums placed at the drainage points.

Net irrigation water use (NIW) was calculated as:

$$NIW\ (m^3\ ha^{-1}) = I - D$$

where I is the supplementary irrigation water applied ($m^3\ ha^{-1}$) and D is the drainage loss ($m^3\ ha^{-1}$).

Rainfall was measured using standard rain gauges installed in each block. It was excluded from the input term because kharif rice in the study area is largely rain-fed.

Irrigation water productivity (IWP) was then calculated as (Ali and Talukder, 2008):

$$IWP\ (kg\ m^{-3}) = (Yr + Yf) / NIW$$

where Yr is the rice grain yield (kg ha^{-1}) and Yf is the fish yield (kg ha^{-1}). For the traditional system, Yf = 0.

The protein output from the integrated system was determined by collecting representative samples of harvested rice grains (1 kg per plot) and fish (three specimens of each species per plot) at the time of harvest. These samples were subsequently analysed at ICAR-Research Complex for NEH Region, Umiam, for protein content, following the standard analytical procedures (AOAC, 2019). The total protein yield per hectare was calculated by multiplying the average protein percentage by the respective total production figures for rice and fish. Protein output was expressed on an edible basis, that is, considering milled rice (with a milling outturn of about 65%) and the edible flesh portion of fish.

The labour requirements were also recorded through the maintenance of day-to-day records by the farmers who participated in this study. Farmers were provided with simple record books for this purpose. The farmers were asked to record the number of laborers employed and the number of hours worked for the major activities in the traditional and integrated systems. The records were verified weekly by the staff of KVK, Ri-Bhoi. Household consumption patterns were monitored through monthly interviews with the participating farm families using a structured questionnaire. The questionnaire was designed to document the quantity of fish harvested, consumed within the household, and sold, along with basic demographic information for each household.

Statistical analysis was performed using SPSS (v. 21.0). Prior to analysis, data were tested for normality and homogeneity of variance. Data from the five years were pooled, and the two systems were compared by one-way analysis of variance, which for two groups is equivalent to an independent samples t-test. Differences among the three fish species were tested by one way ANOVA, and means were separated using Duncan's multiple range test (DMRT) at $p \leq 0.05$. Net returns were calculated as gross returns minus total cost of cultivation, and the benefit-cost ratio (BCR) as gross returns divided by total cost. Total cost comprised field preparation, rice seedlings and transplanting, fish fingerlings, supplementary feed, organic manure and hired labour, following the paid-out cost (Cost A1) concept used by the Commission for Agricultural Costs and Prices. Family labour was recorded in person-days but not valued. The cost of trench, sump and dike construction were charged in full each year rather than amortised, representing a conservative approach that, if anything, understates the BCR of the integrated system.

The integrated paddy-fish system outperformed traditional paddy monoculture in net returns and most environmental parameters over the five year study period (Table 1). Net returns averaged `108,555 $ha^{-1}$ in the integrated system against `44,220 ha^{-1} in monoculture, an increase of 145.5%. The BCR, however, was lower under integration (1.61) than under monoculture (2.18), since fish seed and feed raised the total cost from `37,455 to 179,035 ha^{-1}. The integrated system thus earns more per hectare but less per rupee invested, a distinction that matters for households with limited working capital.

Table 1. Economic performance metrics of paddy-cum-fish integration versus traditional cultivation (2018-2023)

Parameter	Integrated system	Traditional system	p value
Mean annual yield (kg ha^{-1})			
Rice	3,465±156.3	4,500±182.4	<0.01**
Fish	1,050±45.2	–	–
Economic indicators (` ha^{-1})			
Gross revenue	287,590±1,245	81,675±984	<0.001***
Total costs	179,035±865	37,455±456	<0.001***
Net returns	108,555±789	44,220±567	<0.001***
BCR	1.61	2.18	–

Values represent means±SE (n = 40 plots per system). Total costs include: (a) Field preparation (Integrated: `25,500 ha$^{-1}$, Traditional: `12,000 ha^{-1}), which for the integrated system includes annual trench, sump and dike work charged in full each year; (b) Rice seedlings and transplanting (`8,200 ha$^{-1}$); (c) Fish fingerlings (`42,000 ha^{-1}); (d) Fish feed (`56,800 ha$^{-1}$); (e) Organic fertilisers (Integrated: ` 15,535 ha^{-1}, Traditional: `8,255 ha$^{-1}$), and (f) Hired labour costs (Integrated: `31,000 ha^{-1}, Traditional: `9,000 ha$^{-1}$); Family labour was not valued (Cost A1 basis). Unit prices considered: Rice: `18.15 kg^{-1}, Amur carp: `50 kg$^{-1}$, Mrigal: `200 kg^{-1}, Silver barb: `180 kg^{-1}. BCR was computed from mean gross returns and mean total cost; hence no SE is given. Significance levels: *p<0.05, **p<0.01, ***p<0.001

The advantage in net returns is consistent with Roy *et al*. (2024), who reported revenues up to 245% higher for integrated systems in Tripura. Nair *et al*. (2014) likewise reported that organic rice-prawn farming in Kerala gave 20% higher combined net revenue than the conventional rice-prawn system, even though organic rice yield was 23% lower (4,376 *vs* 5,690 kg ha^{-1}). A yield penalty of similar size was observed here (3,465 *vs* 4,500 kg ha^{-1}), although in the present case it is linked to integration rather than to organic management. Higher initial investment in the integrated system, also noted by Islam (2016) in Bangladesh, was recovered from the higher gross revenue. The BCR of the integrated system was close to the 1.65 reported by Saikia and Das (2008) from Arunachal Pradesh, but below the 2.27 recorded by Debnath (2025) in Tripura and the 2.66 to 2.83 reported by Sethi *et al*. (2005) from eastern India. Fingerlings and supplementary feed together accounted for about 55% of the total cost in the present study, and this heavy input expenditure largely explains the lower ratio. The net return advantage of the integrated system over monoculture remained positive every year, ranging from 125.8 to 158.4%, which indicates that the gain was not confined to a few favourable seasons.

The 23% reduction in rice yield contrasts with the 14.3% increase reported by Debnath (2025) from Tripura. Much of this difference is structural. In a square 0.1 ha plot, the 1 m wide peripheral trench and the 2 m x 2 m sump occupy about 126 m^2, or nearly 13% of the plot, so yield expressed on the gross plot area was bound to decline. On the cropped area alone, rice yield in the integrated plots works out to about 3,970 kg ha^{-1}, which is roughly 12% below monoculture. The remaining gap may reflect the deeper standing water maintained for fish, which can restrict tillering, and differences in variety and agro-climate between the two studies.

Fish production averaged 1,050 kg ha^{-1} with a stocking-weighted mean survival of 73.7% across the three species (Table 2). This is appreciably higher than the 326 kg ha^{-1} of common carp reported by Dorothy *et al*. (2024) from Manipur, which may be attributed to the three-species polyculture and the daily supplementary feeding followed in the present study. The 659 kg ha^{-1} obtained by Bhatnagar *et al*. (2021) is less directly comparable, as it refers to the air-breathing *Channa punctatus* rather than a carp polyculture. Amur carp performed best among the three species, with a final weight of 303 g and a survival rate of 78.6%, consistent with Das (2017) on its suitability for hill terrain.

Table 2. Fish production parameters in integrated system (2018-2023)

Species	Survival rate (%)	Final weight (g)	Weight gain (g)	FCR
Amur carp	78.6±2.86^a	303±3.45^a	294.5±3.45^a	1.65±0.08^a
Mrigal	72.4±3.12^b	285±4.23^b	276.5±4.23^b	1.78±0.11^b
Silver barb	68.5±2.95^c	245±3.86^c	236.5±3.86^c	1.92±0.13^c

Values represent means±SE (n=40 plots). Different superscript letters within the columns indicate significant differences (p<0.05). Initial weight was 8.5±0.8 g for all species. FCR: Feed conversion ratio

Environmentally, soil organic carbon was 23% higher and stem borer incidence 65% lower in the integrated plots than in monoculture, without any chemical pesticide use. These trends agree with the gain in soil organic matter summarised by Das (2018) for rice-fish fields of North-east India, and with FAO (2001) and Li *et al*. (2025) on natural pest regulation in integrated systems. Water quality parameters, including dissolved oxygen, pH, and temperature, remained within the optimal ranges throughout the culture period (Table 3). Irrigation water productivity improved by 30% and edible protein output by 40% (Table 4), supporting Roy *et al*. (2024) on the climate resilience of integrated systems and aligning with the sustainability conclusions of Yu *et al*. (2023) from their broader meta-analysis.

Labour requirements rose by 25%, generating additional rural employment but also reflecting the scaling constraint identified by Paramesh *et al*. (2022) in areas facing labour scarcity. Household retention of 45% of fish output points to a meaningful, albeit

Table 3. Water quality parameters under different cultivation systems (2018–2023)

Parameter	Integrated system	Traditional system	P value
Water quality			
Dissolved oxygen (mg l^{-1})	5.8 ± 0.3	4.2 ± 0.2	< 0.01**
pH	6.8 ± 0.2	6.5 ± 0.2	> 0.05^{ns}
Temperature (°C)	26.5 ± 0.8	27.2 ± 0.9	> 0.05^{ns}

Values represent means ± SE (n = 40 plots per system). Significance levels: ns, not significant; *p<0.05; ** p<0.01; *** p<0.001

Table 4. Resources use efficiency metrics in integrated versus traditional cultivation systems (2018-2023)

Parameter	Integrated system	Traditional system	p value
Irrigation water productivity (kg produce m^{-3} irrigation water)	4.52±0.21	3.48±0.18	<0.01**
Edible protein output (kg ha^{-1} year^{-1})	256.4±12.3	183.1±9.8	<0.001***
Labuor requirements (person-days ha^{-1} year^{-1})	285±15.6	228±12.4	<0.01**
Household fish consumption (kg ha^{-1} year^{-1})	472.5±22.4[1]	–	–

Values represent means±SE (n=40 plots per system). Significance levels: *p<0.05, **p<0.01, ***p<0.001. [1]Represents 45% of the total fish production retained for household consumption

secondary, contribution to family nutrition. Certain limitations merit acknowledgement. Indicators such as return on investment (ROI), payback period, gender-disaggregated participation, weed suppression, carbon sequestration, and greenhouse gas emissions were not measured in the present investigation; their inclusion in future studies would further strengthen the evidence base for the economic and environmental viability of paddy-fish integration. Together, these results justify policy support for paddy-fish integration in Meghalaya, in line with the recommendations of the National Academy of Agricultural Sciences (NAAS, 2001) for North-east India and the implementation experience documented by Roy *et al*. (2024) in Tripura. Scaling up will require addressing the labour and yield trade-offs identified, through targeted extension services and adequately resourced institutional support.

Over five years in Ri-Bhoi District, integrating a carp polyculture with rice more than doubled net returns per hectare, improved dissolved oxygen in the field water and raised soil organic carbon, without chemical fertilisers or pesticides. However, these gains were accompanied by a 23% reduction in rice yield, 25% increase in labour requirements and a lower benefit-cost ratio than monoculture, largely because fingerlings and feed accounted for more than half of the total expenditure. Paddy-fish integration therefore shows potential for adoption in Meghalaya, particularly where farmers can meet the higher working capital requirements, supported by institutional credit, local fingerling production and low cost farm made feeds.

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