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# Analyzing the adoption of nutrition-sensitive carp-SIS polyculture technology: evidence from a case study in Bangladesh

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**Introduction:** Small indigenous species (SIS) of fish are rich in micronutrients that are essential to combat the existing malnutrition in Bangladesh. However, their availability is constantly decreasing due to gradual environmental degradation making their availability irregular and hence expensive in the market. Integrating SIS with carps in homestead ponds is being promoted as a form of nutrition-sensitive aquaculture to enhance both production and consumption of these nutrient-rich species. Various improved pond management techniques (IPMTs) are suggested to boost the nutrition-sensitive carp-SIS polyculture.

**Objectives:** This study examines the trends and factors influencing the adoption of IPMTs using the sustainable livelihood framework (SLF) approach. We address the following three key questions: (i) What are the trends in production and consumption of fish, in particular SIS from homestead ponds? (ii) Have farm households adopted or disadopted IPMTs over time? (iii) What are the determinants of adoption and disadoption of IPMTs?

**Methods:** Based on primary data of 234 households from Barishal district from 2014 and 2022, we perform significance tests to compare project and non-project households in 2014 versus 2022 and apply fixed effects Poisson regression and fixed effects negative binomial regression models to identify household decisions to adopt the IPMTs.

**Results and conclusion:** Quantitative survey results indicate a significant increase in the production and consumption of SIS over time. In 2014, the project households exhibited adoption rates of 60% or more for various IPMTs such as stocking of fast-growing species, pre-stocking liming, pond dike construction, fertilizer application, stocking of high quality fish seeds, aquatic weed control, and turbidity management. However, by 2022, some of these IPMTs were disadopted by project households and only a few techniques, including providing sunlight exposure to ponds, pre-stocking liming, and supplementary feeding, were more widely used. Additionally, many non-project households also increased their adoption rates of IPMTs significantly. The fixed effects regression model shows that adoption is positively influenced by the number of household members participating in aquaculture, size of the pond, sole ownership of the pond and the number of years household has been involved in aquaculture. Follow-up activities such as monitoring and training of the project beneficiaries and government support are recommended to support long-term adoption of the IPMTs.

KEYWORDS

adoption behavior, nutrition-sensitive aquaculture, small indigenous species, Poisson regression, negative binomial regression

# 1 Introduction

Malnutrition remains a widespread and persistent problem in rural Bangladesh (WFP, 2022). Adequate dietary diversity plays a crucial role in mitigating malnutrition, particularly among pregnant women and children as poor maternal nutrition often leads to child malnutrition (Ahmed et al., 2016; Blankenship et al., 2020; Tafasa et al., 2023). Consumption of adequate protein and micronutrient rich food is essential to combat micronutrient deficiencies (Ahmed and Waibel, 2019; Bamji et al., 2020).

The diet in Bangladesh is predominantly rice-based, with fish being the second most important and culturally preferred food. Fish is not only the largest and most affordable source of high-quality animal protein, but certain species can also provide essential micronutrients (Bogard et al., 2016; Sheeshka and Murkin, 2002). Small indigenous fish species (collectively referred to as SIS) are particularly valuable in this regard as they are rich in key micronutrients such as Vitamin A, calcium, iron, zinc, and proteins (Ali et al., 2016; Breidenassel et al., 2022; Islam et al., 2023; Kunda et al., 2014). Despite their diminutive size, typically reaching a maximum length of approximately 25 cm (9 inches), some of the SIS are regarded as "natural superfoods" due to their higher essential micronutrient content compared to conventionally farmed fish (Dubey et al., 2024a). These fish provide better nutrition as they are often consumed whole retaining all the accessible nutrients (Islam et al., 2023). SIS are also considered "poor-friendly" because they can be purchased in small quantities, making them accessible to low-income households even when fish prices are high (Saha and Barman, 2020). Moreover, as SIS are usually cooked with vegetables and minimal oil, they contribute to the dietary diversity of the rural poor (Thilsted and Wahab, 2014). As in Bangladesh, people in India also consume these fish whole and this is very much existent within their culture, especially in the North East region (Samal et al., 2024). Similarly, people in Cambodia consume small fish in the form of fish sauce, fish paste and preserved small fish (Islam et al., 2023).

In Bangladesh, about 4.27 million households (20% of the rural population) operate at least one homestead pond (Lam et al., 2022). Despite their potential, these ponds have traditionally been underutilized and mainly dominated by carp species, followed by tilapia and catfish. A variety of SIS such as mola (*Amblypharyngodon mola*), punti (*Puntius sophore*), chapila (*Gudusia chapra*), darkina (*Esomus danrica*), dhela (*Osteobram cotio cotio*), and colisa (*Trichogaster fasciata*) are often found in these ponds that come through run-off during heavy rains and floods (Islam et al., 2023; Rajts and Shelley, 2020). In the past, SIS were abundant in diverse freshwater habitats, ranging from rivers, streams, ponds, beels, ditches and floodplains, and even thrived in lowland areas such as rice fields and wetlands (Kohinoor et al., 2007). However, the stock of SIS has declined in recent years due to loss of habitat and breeding grounds, overexploitation, pollution, pesticide use in agriculture and climate change (Hasan et al., 2002; Rahman et al., 2010). Furthermore, SIS have historically been considered as "weed" or "trash" fish in carp polyculture ponds, competing with carp for food. Consequently, they were eradicated before stocking by completely drying the pond or using pesticides (Castine et al., 2017; Kunda et al., 2014). Indeed, some studies suggest potential competition between species, leading to lower weight gain for Indian Major Carps (IMCs) when co-cultured with SIS (Kohinoor et al., 1998; Roy et al., 2002).

However, it has been increasingly recognized that the presence of SIS is generally a sign of a healthy ecosystem, as they play an important role in the formation of natural food webs (Shepon et al., 2020). The successful integration of SIS such as mola with carps indicates that SIS can be profitably cultured alongside carps, resulting in increased overall pond productivity and nutrient quality (Castine et al., 2017; Dubey et al., 2024a; Rajts and Shelley, 2020; Saha and Barman, 2020). For example, there is evidence of successful carp and mola polyculture in homestead ponds in the northwest Bangladesh (Rajts and Shelley, 2020). Fish production was found to be 27 to 33% higher in ponds stocked with SIS compared to non-SIS ponds in a project carried out in Terai, Nepal (Rai et al., 2012). Dubey et al. (2024b) conducted a study across several districts of Odisha in India and found that when mola broods are added to the carp-mola polyculture system, total fish production increases. Roos et al. (2007) highlighted that the co-culture of nutrient-dense SIS with carps can mitigate micronutrient deficiencies without compromising carp production.

Aquaculture presents a potential solution to address the decreasing availability of SIS for the growing population of Bangladesh (Belton and Thilsted, 2014; Chan et al., 2024). Homestead pond aquaculture, especially polyculture of carps along with SIS (carp-SIS polyculture) allows households to integrate a variety of nutrient-dense fish species into their ponds, making these resources easily accessible (Ahmed and Waibel, 2019). SIS generally have short life cycles and mature within a few months compared to other large fish species (Hasan et al., 2002). During the three-to-four-month period between harvesting and stocking of carp and other fish species, SIS remain in the pond, continue breeding, and improve the efficiency of converting pond resources into fish production. SIS such as mola broodstock can be conserved in the pond as stock for continuing production (Rajts et al., 2023). When small and large fish are farmed together, households can regularly harvest SIS throughout the year for own consumption while selling large carps as a cash crop (Ali et al., 2016; Kunda et al., 2014). Thus, over the past decade, the integration of SIS into conventional carp polyculture has been promoted as a promising nutrition-sensitive innovation that can significantly improve micronutrient intake in farming households, particularly among women and children (Castine et al., 2017; Thilsted et al., 2016).

Aquaculture productivity depends on appropriate use of inputs and management practices (Prodhan and Khan, 2018). The productivity of carp-SIS polyculture system, especially in homestead ponds can be enhanced by adopting various improved pond management practices (Ali et al., 2016). Depending on the size and growth of the fish, supplementary feeding alongside natural food is recommended to boost fish growth, particularly in carp-mola polyculture systems (Dubey et al., 2024b). After introducing SIS, positive impacts on productivity have been found with respect to the carp polyculture system (Dubey et al., 2024a,b; Karim et al., 2016; Prodhan and Khan, 2018; Rahman et al., 2022, 2023) as well as in freshwater prawn farming (Kazal et al., 2020). Similarly, in Nigeria, higher yields and increased income are reported due to the implementation of sustainable aquaculture technologies (Akangbe et al., 2016) and in Myanmar, household welfare increased as reflected in improved fish productivity, income and dietary diversity (Aung et al., 2021). Increases in household consumption and income have been also identified based on regular harvesting of SIS (Castine et al., 2017; Rajts and Shelley, 2020).

Despite the evidence on these positive impacts, small-scale fish farmers often fail to implement proper pond management practices, leading to low productivity in the carp polyculture system (Rahman et al., 2022). Indeed, the awareness of the significance of SIS and IPMTs among Bangladeshi farmers has been relatively low compared to other Asian countries (Bikara, 2020). Furthermore, the few given studies to date have concentrated on the immediate outcomes of aquaculture interventions, with insufficient attention to the sustainability and enduring benefits of these practices. Moreover, the specific advantages of adopting IPMTs in homestead pond polyculture, especially in nutrition-sensitive carp-SIS polyculture, have not been thoroughly explored over time.

Against this background, this paper addresses the following research questions:

1 What are the trends in production and consumption of fish, in particular SIS from homestead ponds?
2 Have farm households adopted or disadopted IPMTs over time?
3 What are the determinants of adoption and disadoption of IPMTs?

Thus, we contribute to the given literature by using a specific case study from Bangladesh. This allows us to base our analyzes on a unique dataset collected from rural households in two waves over a longer period of time. First, we are able to analyze the trend of production and consumption of SIS in particular over time. Second, it enables us to enhance our understanding regarding the rate of adoption and disadoption and the factors determining adoption and disadoption behavior. And third, we apply rigorous econometric analyzes to our primary data and test the robustness of the results. For this, we use different specifications of the regression models. The results are expected to support research and policymaking in developing evidence-based strategies for addressing malnutrition and promoting pond aquaculture in Bangladesh. The paper is organized as follows: section 2 presents the conceptual framework. Section 3 outlines the data sources and methodology employed in this study. Section 4 unveils and discusses the results. Finally, section 5 summarizes some key findings and concludes.

# 2 Conceptual framework

To identify potential determinants of the adoption of IPMTs, the Sustainable Livelihoods Framework (SLF) is used as a conceptual framework (Scoones, 1998). A rural household's livelihood is defined as the capabilities, assets, and activities of a means of living (Ashley and Carney, 1999). The SLF encompasses three main components: the livelihood platform, livelihood strategies, and livelihood outcomes (Figure 1). The livelihood platform consists of different types of capital such as natural capital (e.g., pond area), physical capital (e.g., inputs), human capital (e.g., education), social capital (e.g., extension service) and financial capital (e.g., non-farm income source). Based on this platform, a household formulates its livelihood strategies by combining assets and activities, which ultimately lead to specific livelihood outcomes (Nguyen et al., 2015).

The SLF is well suited for the present study because homestead pond aquaculture plays a vital role in the livelihoods of rural households in Bangladesh. Depending on its access to different types of capital, a household chooses its economic activities (livelihood strategies) in order to improve its well-being (livelihood outcomes). For example, the household could use its natural, physical and human capital to adopt specific IPMTs, thereby improving its overall well-being including income and fish consumption.

# 3 Data and methodology

## 3.1 Data

This study examines data from the European Union (EU) funded Agriculture and Nutrition Extension Project (ANEP) initiated to promote integrated agriculture-aquaculture (IAA) systems in selected districts of Bangladesh and Nepal during 2011–2014 (Jahan et al., 2015). The fundamental objectives of ANEP were: (1) To improve food security and nutrition of smallholders by encouraging the adoption of productive and environmentally sustainable agricultural technologies that improve livelihoods; and (2) to develop market linkages to boost food and nutritional security of both rural producers and urban consumers of Bangladesh. WorldFish led the technology transfer and aquaculture related activities, providing technical support to its implementing partner, the Community Development Centre in Bangladesh (CODEC).

The ANEP provided training on integrated aquaculture-agriculture-based technologies, focusing on promoting carp polyculture with nutrient dense SIS among resource-poor households in the Barishal district (Jahan et al., 2015; Ali et al., 2016). This district is located in the south-central region of Bangladesh. The project targeted households purposively, meaning that households had to have at least one homestead pond. A total of 1,909 ponds were selected for the program in Bangladesh. For knowledge dissemination, ANEP employed a group approach organizing 99 farmer groups and selecting 117 lead farmers to continue supporting community fish farmers even after the project ended, thereby enhancing farming skills of these farmers. The project also adopted a family-based approach to increase women's participation in project activities, aiming to build their capacity to address technical and nutritional issues (Jahan et al., 2014).

Over 3 years, the project provided continuous training on simple, low-cost and scientifically proven pond management practices (Jahan et al., 2014). As a part of the monitoring and evaluation, WorldFish designed an assessment to measure the project's impact using a quantitative approach. Households were sampled from both project and non-project villages for the survey. The quantitative surveys were

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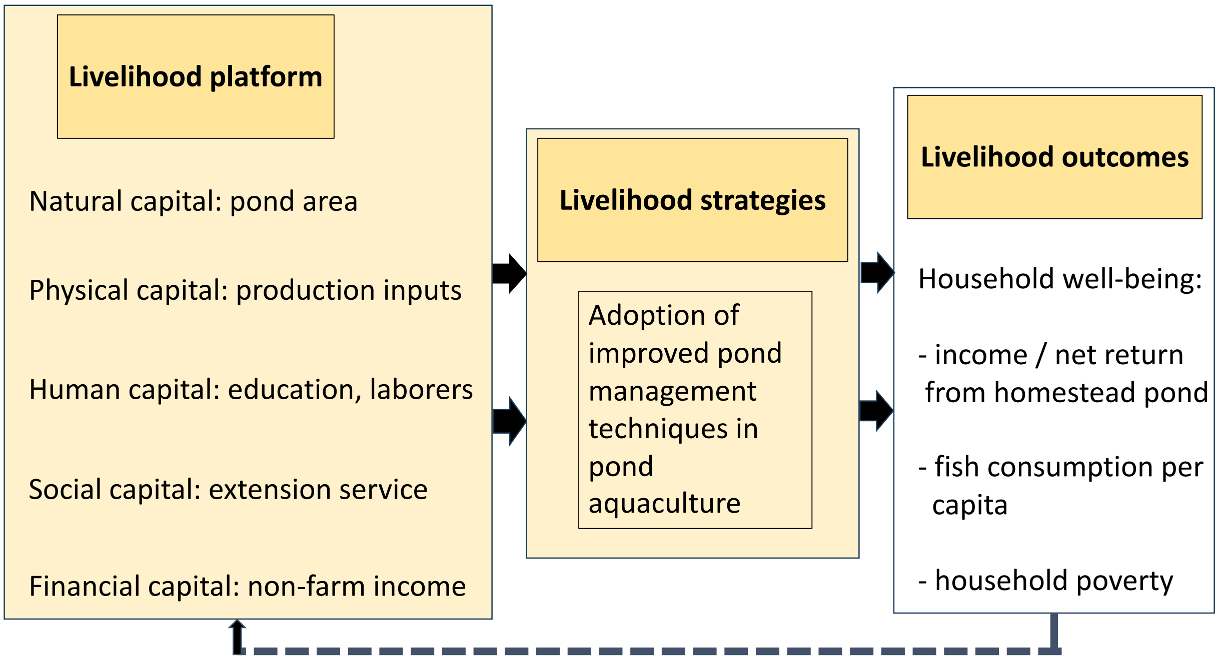


FIGURE 1
The sustainable livelihood framework to identify determinants of adopting IPMTs in pond aquaculture (modified from Chung, 2012).

conducted at the end of the production cycles in 2012, 2013, and 2014 using a semi-structured questionnaire. The data collected in 2014 was used to capture the immediate effects after the project intervention was completed.

In 2021, a follow-up project called "Taking nutrition-sensitive carp-SIS polyculture technology to scale" was funded by the German Federal Ministry for Economic Cooperation and Development (BMZ), aimed to assess social and economic factors influencing the adoption, diffusion, adaption and disadoption of carp-SIS polyculture technology in Bangladesh. As part of the project, a second survey round was conducted in 2022 with the same households to evaluate the long-term effects of the project intervention.

Households from both project and non-project villages in three selected upazilas (sub-districts) Hizla, Mehendiganj and Muladi in Barishal District were sampled to compare the differences in fish production, consumption and income as a result of technological intervention (Figure 2). A balanced panel dataset of 234 households from each round is used in this paper; 119 households belong to the project group and 115 households to the non-project group.

Data collection involved face-to-face, semi-structured quantitative interviews with the farm households, covering demographic, economic, and social aspects, as well as detailed information of the pond, management practices (pond preparation, inputs, feeding), productivity, costs and returns of pond production. Respondents from both project and non-project households were asked about their willingness to participate in both survey rounds. Only those who agreed were interviewed, prioritizing their comfort and privacy, and keeping all identities anonymous. The baseline survey was conducted using pen and paper personal interviews (PAPI), while the follow-up survey utilized the KoboToolbox software on tablets as computer assisted personal interviews (CAPI).

## 3.2 Data analysis

To address the research questions outlined in the introduction, this study employs descriptive statistics followed by explorative regression models. The data analysis was done using statistical software STATA version 16. The choice of regression models was informed by an initial examination of the descriptive results. The descriptive results are disaggregated by project and non-project households for year 2014 and 2022. T-tests were used to determine whether the difference between project and non-project households are statistically significant. Additionally, we performed t-tests comparing project households in 2014 versus 2022 and non-project households in 2014 versus 2022 to assess significant differences over time.

For this paper, we focus on 12 specific IPMTs: pond dike construction, sunlight exposure, aquatic weed control, predatory species control, turbidity control, pre-stocking liming, stocking of quality fish seeds, fingerling acclimatization, stocking of fast-growing species, fertilizer application, natural food investigation and supplementary feeding.

To identify the determinants influencing households' decisions to adopt these techniques, a fixed effects Poisson regression model and a fixed effects negative binomial regression model are used. The dependent variable is continuous, representing the number of IPMTs adopted by each household. Since the households made discrete decisions about adopting these techniques, which can be aggregated to a Poisson distribution, the Poisson regression model for panel data is appropriate. The model is expressed in Equation 1 as follows:

$$E\left(y|X_{\mathrm{it}}\right) = \mu = \exp\left(\beta_i X_{it} + \mu_{it}\right). \quad (1)$$


FIGURE 2
Map of Barishal district of Bangladesh showing the study sites. P, project households; NP, non-project households.

Here, $y$ ($y = 0, 1, 2, 3\ldots 0.12$) represents the number of IPMTs adopted by households in their respective ponds. $X_{it}$ includes explanatory variables such as- human capital (e.g., household demography), physical capital (e.g., pond size and farm size), social capital-(e.g., access to extension service and community membership) and financial capital- (e.g., household loan), and other control variables.

After performing the Poisson regression, we find that the $p$-value from the Hausman chi-square test is less than 0.05, suggesting that a fixed effects Poisson regression is more appropriate than a random effects model. For robustness check, we also conducted a negative binomial regression simultaneously with the Poisson regression, which is also well-suited for continuous dependent variables. The results of the negative binomial regression are very similar, with only minor differences in standard errors compared to Poisson regression. The index of dispersion, presented below the regression coefficients, which is the ratio of variance to mean, is equal to 1. This confirms that the chosen dependent variable—the total number of improved pond management practices adopted—follows a Poisson distribution, suggesting that either regression model can be reliably used.

## 3.3 Description of the sample

The basic characteristics of project and non-project households were quite similar in the first year, 2014, particularly in terms of household size, the age and education of household head, and the number of household members participating in aquaculture (Table 1). However, the overall household size slightly decreased from 2014 to 2022. Notably, the percentage of male-headed households was higher among non-project households compared to project households in 2014, but by 2022, this difference had narrowed, and the two groups were very similar.

In terms of agricultural landholding, project households had a slightly larger average landholding compared to non-project households in both 2014 and 2022. However, overall landholding decreased for both groups by 2022, likely reflecting a shift from solely farm-based activities to a more diversified mix of farm and non-farm income-generating activities. Project households had more frequent exposure to agricultural extension services in both years (21% in 2014 and 25% in 2022) compared to the non-project households (10% in 2014 and 15% in 2022). The proportion of households with non-farm income sources remained similar between the two groups and across

TABLE 1 Socio-demographic profile of sampled households in Barishal, 2014 and 2022.

| | 2014 | | | 2022 | | |
|---|---|---|---|---|---|---|
| | P | NP | All | P | NP | All |
| Number of people living in household (mean) | 5.0 | 5.4 | 5.2 | 4.8 | 4.9 | 4.8 |
| Age of household head (mean) | 43.5 | 44.7 | 44.1 | 53.4 | 51.6 | 52.5 |
| Household is male-headed (%) | 78.2 | 91.3 | 84.6 | 95.0 | 93.9 | 94.4 |
| Household head's education—class 1–16 (mean) | 5.4 | 5.2 | 5.3 | 4.7 | 6.1 | 5.4 |
| Number of working-aged (15–64 years) household members (mean) | 2.9 | 3.1 | 3.0 | 3.1 | 3.1 | 3.1 |
| Agricultural land owned excluding pond (ha) | 0.43 | 0.36 | 0.40 | 0.30 | 0.21 | 0.25 |
| Number of household members participated in aquaculture in last 12 months (mean) | 3.0 | 2.6 | 2.8 | 2.7 | 2.3 | 2.5 |
| Number of years household has been involved in aquaculture (mean) | 8.3 | 10.1 | 9.2 | 18.3 | 20.1 | 19.2 |
| Household has been contacted by extension service in last 12 months (%) | 21.0 | 9.6 | 15.4 | 25.2 | 14.8 | 20.1 |
| At least one household member is member of any community organization (%) | 26.0 | 39.1 | 32.5 | 55.5 | 48.7 | 52.1 |
| At least one member of household has non-farm income source (%) | 78.1 | 80.0 | 79.0 | 75.6 | 75.6 | 75.6 |
| Monthly *per capita* expenditure (USD) | 31.7 | 29.7 | 30.7 | 52.5 | 48.8 | 50.7 |
| Household experienced flood in last 5 years (%) | 19.3 | 6.1 | 12.8 | 72.3 | 73.9 | 73.1 |

P, project households; NP, non-project households; per capita expenditure values are adjusted for inflation in 2022.

both years. *Per capita* monthly expenditure increased for both groups from 2014 to 2022, yet remained comparable between the groups in both survey rounds.

As for households affected by flooding, over 70% of both project and non-project households experienced flooding in the last 5 years in 2022, a significant increase compared to 2014, when only 19% of project and 6% of non-project households reported flood events in 2014.

As shown in Table 2, the size of these sample ponds remained consistent across both survey rounds and between the two groups. In each round, households managed approximately 0.07–0.08 ha as their main homestead ponds with an additional 0.01–0.02 ha of dike area. Since the ponds are homestead ponds, their distances from homesteads are within the range of 25–35 m. In terms of ownership in 2014, almost 60 and 65% of project and non-project households solely owned the ponds respectively, which became 52 and 45% project and non-project households, respectively, in 2022. Moreover, 96 and 91% of the ponds belonging to project and non-project households, respectively, were perennial in 2022, which means that the ponds had at least some fish throughout the year.

# 4 Results and discussion

## 4.1 Production and consumption of fish from pond aquaculture

### 4.1.1 Fish production

Figure 3 depicts the total fish harvest by species for both project and non-project households. Overall, the total fish harvest per ha was much lower compared to the national average which was 5,276 kg per ha in 2021–22 (DoF, 2022). In 2014, project households harvested approximately 2,115 kg per ha, which nearly doubled to 4,120 kg per ha in 2022. For non-project households, the total fish harvest was lower than for the project households, but more than doubled from 1,445 kg per ha in 2014 to 3,368 kg per ha in 2022. Most of this increase is attributed to carps, but the harvest of SIS, catfish and other fish also played a notable role. The harvest of SIS even more than tripled over the period for project and non-project households. Adoption of pond management practices enhanced both carp and mola production in the polyculture system (Ali et al., 2016). Similar positive trends in fish production were observed in other regions of the ANEP project such as in Nepal, where positive impacts on production were seen after 2 years of continuous training on IPMTs (Jahan et al., 2014). Additionally, the use of higher quality feed and fertilizers as part of semi-intensive pond management led to increased fish production in northern Vietnam (Pucher et al., 2014).

### 4.1.2 Fish consumption

Table 3 shows how the households utilize their own harvested fish. The majority of fish harvested from homestead ponds is consumed within the households, and only a portion is sold. Both consumption and sales of fish increased significantly for project and non-project households over time, with sales being significantly lower for non-project households ($p$-value < 0.000). However, while the amount consumed increased, the ratio of consumption to harvest decreased. For project households, the consumption to harvest ratio decreased from 82% in 2014 to 56% in 2022 and for the non-project households, the ratio decreased from 87% in 2014 to 73% in 2022. While when calculating the sales to harvest ratio, for project households, it increased from 18% in 2014 to 41% in 2022 and for non-project households, it increased from 13% in 2014 to 27% in 2022.

Figure 4 shows the different sources from where the households obtained fish for consumption. The majority of households consumed fish by purchasing it at the market in 2022. This shift from 2014 is in line with the decreased ratio of consumption to harvest from Table 3. This trend suggests increased purchasing power and a greater availability of fish in local markets, probably due to the proximity of upazilas (sub-districts) to rivers such as the *Kirtonkhola* and *Meghna*. As fish harvests have increased, households are selling more of their production in 2022 compared to 2014, allowing them to purchase a wider variety of fish from the market rather than relying solely on their pond production. This shift is also attributed to overall income

TABLE 2 Description of the sample ponds in Barishal, 2014 and 2022.

| | 2014 | | | 2022 | | |
|---|---|---|---|---|---|---|
| | P | NP | All | P | NP | All |
| Water surface area of pond (ha) | 0.08 | 0.08 | 0.08 | 0.07 | 0.07 | 0.07 |
| Dike area (ha) | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.02 |
| Distance of pond from home (meter) | 26.3 | 25.7 | 26 | 35.4 | 25.3 | 30.5 |
| Ponds are solely owned by household (%) | 59.7 | 65.2 | 62.4 | 51.7 | 45.0 | 48.5 |
| How old is pond in years (mean) | 18.1 | 19.6 | 19.0 | 28.1 | 29.0 | 28.6 |
| Ponds are perennial (%) | – | – | – | 95.6 | 91.0 | 93.4 |

P, project households; NP, non-project households.

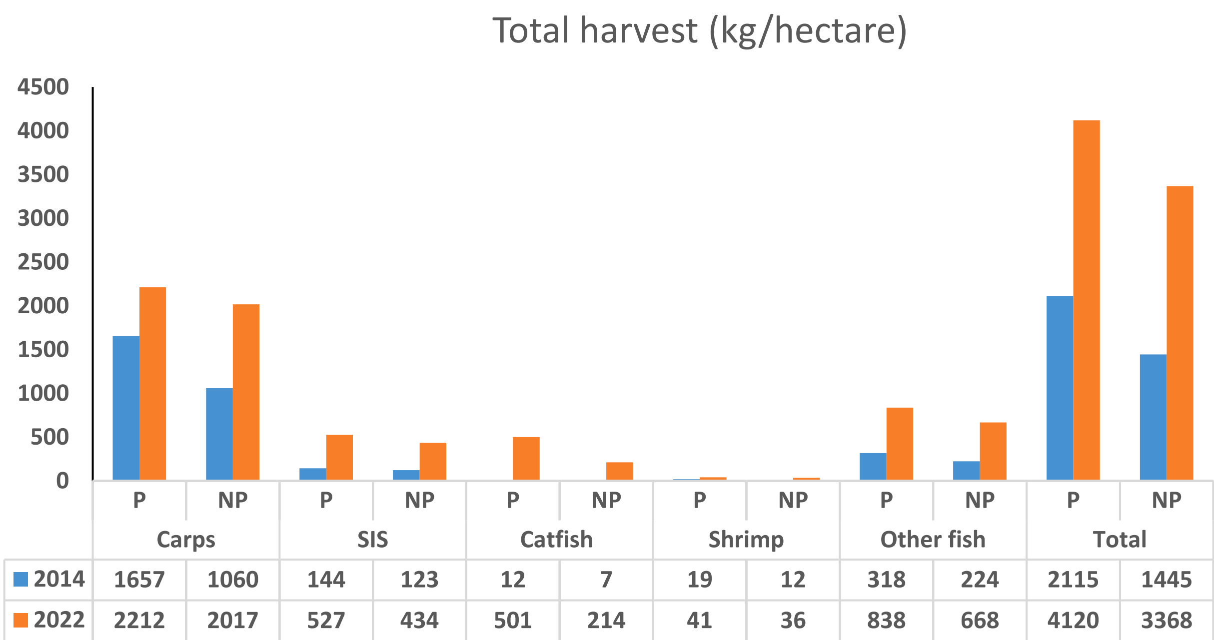


FIGURE 3
Total harvest by species (kg/ha). P, project households; NP, non-project households.

growth over the past decade, which has enabled even lower-income consumers to purchase more fish (Ahmed and Waibel, 2019).

Table 4 shows the *per capita* total fish consumption from all sources and it has significantly increased over time for project as well as non-project households. While consumption amounted to an average of 61–65 g per day and per person in 2014, it increased to 92–97 g in 2022. This increase, ranging between approximately 28–36 g per day, is statistically significant at the 1% level for both household groups. When disaggregating by fish species, the consumption of SIS shows a significant increase. Although non-SIS consumption remains higher, the increase in SIS consumption is more pronounced among project households, with *p*-values below 0.1, while it is not statistically significant for non-project households.

## 4.2 Adoption and disadoption of IPMTs

Table 5 shows the adoption rates of IPMTs among project and non-project households in 2014 and 2022. While initial adoption of all 12 technologies was high immediately after project intervention in 2014, the sustainability of these practices was inconsistent at the time of the second survey in 2022. In 2014, project households adopted significantly more IPMTs than non-project households ($p < 0.001$). For example, around 71% of project households constructed pond dikes compared to 49% of non-project households. The highest adoption rates among project households in 2014 were observed for the following IPMTs: stocking of fast-growing species (94%), pre-stocking liming (80%), construction of pond dikes (71%), fertilizer application (70%), identifying quality fish seed for stocking (69%), control of aquatic weeds (67%) and turbidity control (60%). However, less emphasis was put on practices such as acclimatizing fingerlings before stocking (42%), controlling predatory species (40%), and supplementary feeding (22%).

By 2022, nearly a decade after the initial intervention, there was a noticeable decline in the adoption of certain IPMTs such as pond dike construction, aquatic weed control, predatory species control, turbidity control and different activities related to stocking as well as natural food investigation. However, both project and non-project

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TABLE 3 Use of harvested fish from homestead pond, 2014 and 2022.

| | 2014 | | | 2022 | | | Diff (P2022-P2014) | Diff (NP2022-NP2014) |
|---|---|---|---|---|---|---|---|---|
| | P | NP | Diff | P | NP | Diff | | |
| Total harvest quantity (kg per ha) | 2114.8 | 1444.6 | 670.2*** | 4120.0 | 3368.3 | 751.6* | 2005.2*** | 1923.7*** |
| Quantity sold (kg per ha) | 384.2 | 191.4 | 192.8** | 1706.8 | 910.3 | 796.5* | 1322.6*** | 718.9*** |
| Consumed quantity (kg per ha) | 1730.6 | 1253.2 | 477.4*** | 2347.0 | 2451.3 | −104.2 | 616.4*** | 1198.1*** |

P, project households; NP, non-project households; *, **, and *** indicate significant at 10, 5, and 1% level, respectively.

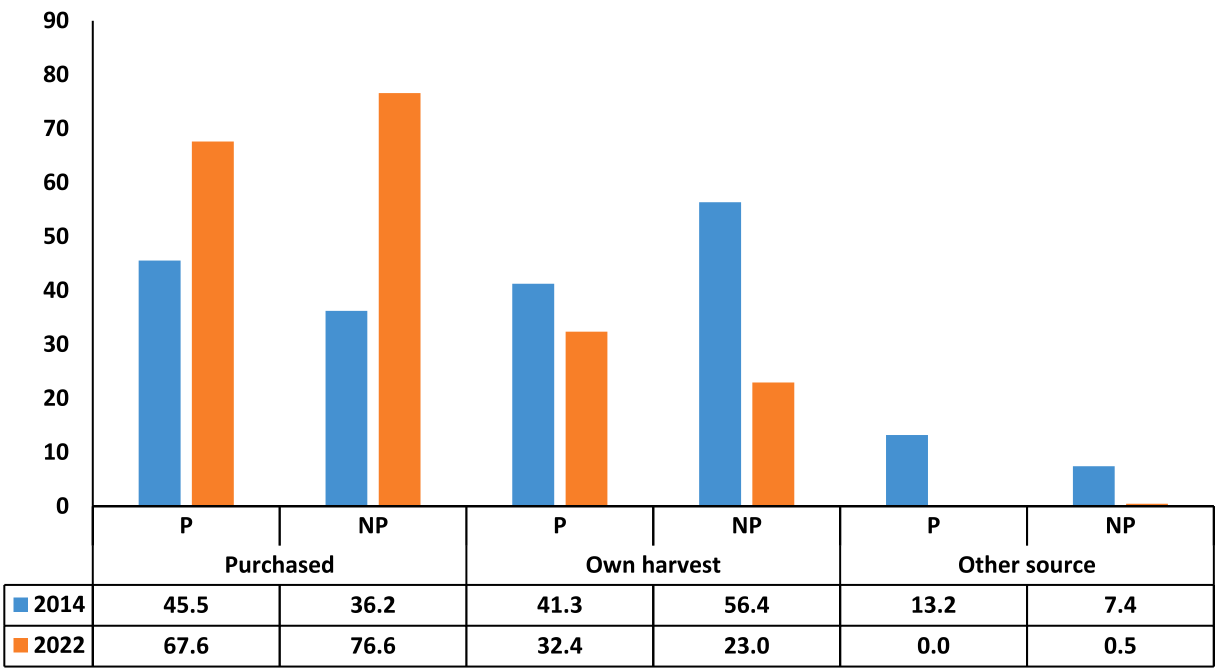


FIGURE 4
Share of fish source for consumption (percentage of households).

households showed an increase in the use of practices such as exposing ponds to sunlight, pre-stocking liming and supplementary feeding. The project households increased the adoption of supplementary feeding significantly from 23% in 2014 to 79% in 2022. The non-project households also increased supplementary feeding by about 64% over the same period. Despite these increases, the differences in IPMT adoption rates between project and non-project households were not statistically significant in 2022. However, many non-project households increased their adoption rates of IPMTs significantly, indicating spillover effects from the initial project implementation in 2014. The findings imply that if beneficiaries had received ongoing monitoring or refresher training after the project concluded, the project outcomes might have been even more beneficial.

## 4.3 Determinants of adoption

Despite the various advantages of adopting IPMTs, the farmers in the study area did not sustain their use over time. Understanding the factors influencing adoption and disadoption is essential. We applied the SLF framework to examine the determinants of these practices, particularly in homestead ponds. The SLF is well suited for the present study as homestead pond aquaculture is an essential component of rural livelihoods in Bangladesh, especially in the Barishal district. Households choose their economic activities based on their access to various forms of capital to improve their well-being (livelihood outcomes). In our analysis, dependent variables representing different capitals of the SLF approach were used as potential determinants of the livelihood strategy toward intensifying pond aquaculture by adopting more IPMTs. For example, variables such as household head information and household size represent human capital, while variables such as non-farm income sources and loan acquisition represent financial capital. Additionally, household exposure to flooding in the last 5 years represents the vulnerability context of the SLF.

The fixed-effect Poisson regression and the fixed effects negative binomial regression show similar results (Table 6). They both show that the significant determinants of IPMT adoption are the number of household members participating in aquaculture ($p < 0.01$), pond size ($p < 0.05$), sole ownership of the homestead pond ($p < 0.1$) and number of years a household has been involved in aquaculture ($p < 0.01$) (Table 6). However, our results are contrary to some findings from other studies. With respect to pond size, Karim et al. (2016) found that fish yield was significantly higher in small ponds than in larger ponds

TABLE 4 Consumption of fish *per capita* per day from all sources (gram per day per person), 2014 and 2022.

| | 2014 | | | 2022 | | | Diff (P2022-P2014) | Diff (NP2022-NP2014) |
|---|---|---|---|---|---|---|---|---|
| | P | NP | Diff | P | NP | Diff | | |
| SIS | 13.7 | 17.6 | −3.9 | 39.9 | 38.0 | 1.9 | 26.2*** | 20.4*** |
| non SIS | 47.6 | 47.5 | 0.1 | 57.0 | 54.7 | 2.2 | 9.3* | 7.2 |
| All fish | 61.4 | 65.1 | −3.7 | 96.9 | 92.7 | 4.2 | 35.5*** | 27.6*** |

P, project households; NP, non-project households; *, **, and *** indicate significant at 10, 5, and 1% level, respectively.

TABLE 5 Adoption of improved pond management practices (in percentage of households), 2014 and 2022.

| | 2014 | | | 2022 | | | Diff (P2022-P2014) | Diff (NP2022-NP2014) |
|---|---|---|---|---|---|---|---|---|
| | P | NP | Diff | P | NP | Diff | | |
| Supplementary feeding | 22.7 | 6.9 | 15.7*** | 79.0 | 71.3 | 7.7 | 56.3*** | 64.3*** |
| Sunlight exposure | 54.6 | 22.6 | 32.0*** | 79 | 73 | 5.9 | 24.4*** | 50.4*** |
| Pre stocking liming | 79.8 | 42.6 | 37.2*** | 93.3 | 92.2 | 1.1 | 13.4*** | 49.6*** |
| Fertilizer application | 69.7 | 33.0 | 36.7*** | 68.1 | 65.2 | 2.8 | −1.7 | 32.2*** |
| Turbidity control | 59.7 | 20.9 | 38.8*** | 31.1 | 39.1 | −8 | −28.6*** | 18.3*** |
| Control of aquatic weeds | 67.2 | 35.6 | 31.6*** | 56.3 | 52.2 | 4.1 | −10.9* | 16.5** |
| Control of predatory species | 40.3 | 11.3 | 29.0*** | 26 | 24.3 | 1.7 | −14.3** | 13.0*** |
| Natural food investigation | 39.5 | 7.8 | 31.7*** | 13.4 | 19.1 | −5.7 | −26.0*** | 11.3** |
| Acclimatize fingerlings before release | 42.0 | 20.9 | 21.1*** | 26.9 | 24.3 | 2.5 | −15.1** | 3.5 |
| Construction of pond dikes | 71.4 | 48.7 | 22.7*** | 52.9 | 46.1 | 6.8 | −18.5*** | −2.6 |
| Quality fish seed identified for stocking | 68.9 | 43.5 | 25.4*** | 25.2 | 25.2 | 0 | −43.7*** | −18.3*** |
| Stocking of fast-growing species | 94.1 | 77.4 | 16.7*** | 33.6 | 34.8 | −1.2 | −60.5*** | −42.6*** |

P, project households; NP, non-project households; *, **, and *** indicate significant at 10, 5, and 1% level, respectively.

because pond management, not pond size, was the key to higher yields. Our finding that sole pond ownership positively influences adoption is also not consistent with Rahman et al. (2020) who found no significant association between pond ownership and adoption of improved shrimp cultivation practices. However, with respect to the number of years involved in aquaculture, Boateng et al. (2022) also found that aquaculture knowledge positively influenced pond aquaculture adoption which is in line with our result.

While the number of years being involved in aquaculture played a role in our case study, the contact to extension service was not correlated with IPMT adoption (Table 6). This can be explained by the fact that our sample households are not involved in commercial aquaculture and hence, they are not expected to be associated with the extension service. In contrast, Rahman et al. (2020) identified training and extension contact as positive influences on the adoption of improved shrimp cultivation practices. Contact with extension agents also significantly contributed to the adoption of aquaculture technologies in Delta State, Nigeria (Agbamu and Orhorhoro, 2009) and in Ghana (Boateng et al., 2022).

Our findings further show that gender, the level of education, non-farm income and the area of agricultural land owned are not associated with the uptake of improved pond management techniques (Table 6). In contrast, Rahman et al. (2023) suggested that factors such as spouse's education level, and off-farm income positively influence technology adoption in pond polyculture. Boateng et al. (2022) showed that age and gender positively influence pond aquaculture adoption. Conversely, farm size and credit constraints reduced adoption rates in commercial aquaculture farms in Bangladesh (Prodhan and Khan, 2018).

## 4.4 Determinants of disadoption

With respect to disadoption, our findings suggest that households with higher average rainfall over the past 5 years are more likely to disadopt IPMTs (Table 6). This result is highly significant in our case and aligns with the work of Ahmed and Diana (2015), who demonstrated that fluctuations in rainfall and flood can adversely affect pond aquaculture. While floods can increase fish productivity by replenishing groundwater, create wildlife habitat, create flood plains and restore soil fertility, they may also cause direct or indirect fish mortality depending on the severity and flood management (Poff, 2002).

Additionally, households with at least one member in a community organization are more prone to disadopt IPMTs. This result contrasts with Boateng et al. (2022) who found a positive correlation between community membership and adoption behavior. However, this can be explained by the fact that women in our study site in Barishal are mostly members in organizations which do not relate in any way to aquaculture or the adoption of IPMTs. Finally, we find that households with older heads and larger household size are more prone to disadopt IPMTs. However, these results are only slightly significant. While we did not identify any further

TABLE 6 Determinants of adoption of improved pond management practices.

| | Total number of IPMTs adopted by households | |
|---|---|---|
| | Fixed effect Poisson regression | Fixed effect negative binomial regression |
| Log of age of the household head | −0.195* (0.111) | −0.195* (0.109) |
| Household head is male (=1) | 0.111 (0.099) | 0.111 (0.103) |
| Highest level of education of the household head | 0.008 (0.009) | 0.007 (0.009) |
| Log of the average household size | −0.174* (0.105) | −0.174 (0.109) |
| Number of household members participating in aquaculture | 0.088*** (0.024) | 0.087*** (0.027) |
| Number of household members between 15 and 64 years | 0.012 (0.028) | 0.012 (0.030) |
| Household has at least one non-farm income source (=1) | −0.007 (0.067) | −0.007 (0.073) |
| Household has taken loan in last 1 year (=1) | 0.006 (0.070) | −0.006 (0.076) |
| Area of agriculture land owned (ha) | −0.034 (0.092) | −0.033 (0.098) |
| Log size of pond (ha) | 0.103** (0.040) | 0.103** (0.041) |
| Homestead pond is solely owned by household (=1) | 0.110* (0.061) | 0.110* (0.060) |
| Household has been contacted by government extension service (=1) | 0.058 (0.076) | 0.058 (0.075) |
| At least one household member is a member of a community organization (=1) | −0.131** (0.060) | −0.131** (0.060) |
| Household has faced flood in last 5 years (=1) | 0.083 (0.069) | 0.082 (0.070) |
| Jack-knifed average years of aquaculture involvement | 0.095*** (0.025) | 0.095*** (0.026) |
| Average rainfall in last 5 years | −0.029*** (0.007) | −0.029*** (0.008) |
| Chi sq. value for Hausman fixed versus random effect test | 69.59 ($p$-value = 0.000) | |
| Index of dispersion | 1 | |

*, **, and *** indicate significant at 10, 5, and 1% level, respectively.

determinants which are correlated with the disadoption of IPMTs in Bangladesh, Agbamu and Orhorhoro (2009) identified barriers such as difficulties in obtaining microcredit, inadequate fisheries extension services, and high cost of pond construction and fish feed as key factors preventing Nigerian households from continuing pond management practices.

## 5 Summary and conclusion

The Agriculture and Nutrition Extension Project strives to alleviate malnutrition and inadequate dietary diversity by promoting improved pond management practices to homestead pond producers. The underlying objective of this project is to ensure higher and sustainable production of the carp-SIS polyculture system. Hence this paper examines the trend in fish production and consumption from homestead ponds, the adoption and disadoption of IPMTs over time and finally the determinants of adopting and disadopting IPMTs.

We find that over the study period, the total harvest of fish, especially SIS, tripled. But not only the overall fish production showed a significant increase, also fish consumption and fish sales increased over time. Both the fish produced in the homestead ponds and the diversity of fish purchased from the income fish sales at the market have contributed to an increase in *per capita* fish consumption and a greater variety of fish being consumed.

In terms of IPMT adoption, project households initially adopted more practices than non-project households in 2014. However, by 2022, nearly a decade post intervention, project households had disadopted several IPMTs. Both the adoption and disadoption over the years have been analyzed by several socio-demographic factors inspired from the sustainable livelihood approach. The Poisson regression results indicate that adoption is positively influenced by the number of household members engaged in aquaculture, pond size, household sole ownership of the homestead pond, and the number of years the household has been involved in aquaculture. Households especially with higher average rainfall over the past 5 years are more likely to disadopt IPMTs.

To gain a more comprehensive understanding of the SLF approach in this context, further research is needed especially on the effects of diversified pond aquaculture on livelihood outcomes, such as household well-being. In this context, it has to be pointed out that this study has some limitations. A notable limitation of this study is its geographic focus on a region in South Bangladesh that is adjacent to a major river and prone to flooding. The livelihoods of the local population are closely tied to artisanal fisheries, with a heavy reliance on wild-caught fish from rivers. The widespread availability of river fish, including SIS, in local markets further reinforces this dependency. Additionally, fish entering ponds through runoff complicates the dynamics, presenting significant challenges to the implementation of IPMT interventions. Had the intervention targeted a region less connected to rivers or with fewer fish stocks, it is plausible that the interventions had fewer obstacles and could have achieved greater success. This assumption is supported by the successful implementation of similar interventions in Nepal, as documented by Jahan et al. (2015), where pond aquaculture is less prevalent than in our study site in Bangladesh. Thus, research is needed from other geographical locations.

The results of this paper suggest several policy implications. The first and most important step should be to ensure that the SIS stock is available to households. The fish farmers should be encouraged to stock brood SIS in dedicated hatcheries as mentioned in Dubey et al. (2023). Promoting the adoption of hatchery-produced SIS seed, which is uniform in size and age and less prone to pathogen infections could also enhance the success of such projects. Second, awareness related to the benefits of SIS consumption and their sustainable production should be increased both at the individual and at the small-scale fish producer community level. Grassroot organizations and extension services targeting small-scale fish producers, particularly women, could help raise awareness of SIS production and its important role in consumption and prevention of malnutrition. Third, adopting climate-resilient aquaculture strategies as suggested by Hossain et al. (2021) are crucial to minimize rainfall variability that has been found to pose significant risks to the aquatic farming activities resulting in disadoption of IPMTs. Finally, it should be noted that successful implementation and scaling up of nutrition-sensitive aquaculture requires collaboration among key stakeholders, including international organizations, researchers, policymakers, government and non-governmental organizations, and fish farming communities.

## Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

## Author contributions

NH: Data curation, Formal analysis, Methodology, Writing – original draft, Writing – review & editing. UG: Conceptualization, Funding acquisition, Project administration, Resources, Supervision, Writing – review & editing. SD: Funding acquisition, Project administration, Supervision, Writing – review & editing.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

## Publisher's note



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