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IMPACT OF COMMERCIAL STRIPED CATFISH (*PANGASIANODON HYPOPHTHALMUS*) FARMING ON FARMERS' LIVELIHOOD AND ENVIRONMENT IN BANGLADESH

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ABSTRACT:

Striped catfish, *Pangasianodon hypothalamus* (Sauvage, 1878), has gained popularity among the Bangladeshi commercial fish farmers because of its rapid growth and high tolerance of adverse ecological conditions. The study aims to examine the impact of farmers' socio-economic and farming features on their livelihood outcomes of Pangas (LOP), considering the sustainable livelihood approach (SLA) and the negative impacts of commercial farming activities on the surrounding environment using a mixed-method approach. A quantitative survey was conducted using a pre-tested structured questionnaire, and qualitative data were explored through focus group discussions (FGDs), in-depth interviews (IDIs), and key informant interviews (KIIs) to assess the impact. Data were computed using descriptive statistics, rank order, correlation coefficient, and regression analysis. In terms of LOP, the highest progress was observed in human capital (87.5%), followed by physical capital (75.7%), financial capital (70%), social capital (55.7%), and natural capital (38%). The farmers' education, experience, knowledge of fish farming, and adoption of modern farming technology correlated positively, whereas age correlated negatively with the LOP and significantly impacted the achievement of the outcomes. Farming intervention was encouraged to establish various upward and backward linkage industries and create employment opportunities, which contributed to economic progress. On the other side, rapid expansion of pangas farming impacted the surrounding environment by converting two or more croplands (37%) into a closed pond and discharging polluted water (52%) and bottom sludge (49%) into natural water bodies. Raising dikes of fish ponds caused waterlogging in the crop field during cultivation, which also hampered the navigation of aquatic animals during the breeding season. Moreover, harmful chemical discharges were blamed for the decline of aquatic animals. Therefore, it is necessary to implement sustainable aquaculture practices along with proper monitoring and evaluation processes to ensure safe aqua-food production in an environmentally friendly manner, thereby achieving sustainable development goals.

KEYWORDS: Commercial farming, Environmental impacts, Livelihood outcomes, Pangas, SDGs.

1. INTRODUCTION

Aquaculture production around the world plays a significant role in meeting people's dietary protein demands. Over the last two decades, there has been an increasing recognition of the fisheries and aquaculture sectors for their essential contribution to global food security and nutrition (FAO, 2022). Viet Nam is the world's leading exporter of striped catfish that implements good aquaculture practices (GAP) and enhances its revenue earnings by exporting high-quality fish (FAO, 2023). Ninety percent of aquaculture production takes place in developing countries, serving as a primary source of animal protein in diets and enhancing food security through domestic consumption and economic growth from exports (Anderson *et al.*, 2017). Bangladesh ranked third in inland fisheries behind China and India and fifth in aquaculture production in 2021–22 (FAO, 2022, DoF, 2023). Many countries introduce faster-growing exotic species from different regions to advance aquaculture production (Gu *et al.*, 2022; Paul *et al.*, 2022). Although Bangladesh introduced striped catfish, locally called pangas, in 1993 (Rahman, 2005, DoF, 2022), the production boom started after introducing the modern variant at the beginning of the recent century (Khan *et al.*, 2018). Now, farming this species has become more cost-effective (Haider *et al.*, 2023) and beneficial to farmers' profit margins (Ali *et al.*, 2011).

Low initial investment, a simple culture technique, higher consumer demand, and effective feed conversion ratio have made it a popular fish for the aquaculturists in Bangladesh. Young educated farmers are showing interest in this species (Haider *et al.*, 2023). Thus, commercial pangas farming has opened new employment opportunities for unemployed youth in Bangladesh. Pangas has a significant contribution to food security as a fish for the poor and a delicious protein source for the children because of its low cost and low bone characteristics, as fish is the major contributor of animal protein supply (67%) for consumption in Bangladesh (DoF, 2022). The fisheries sector contributed 2.4% to the national GDP, while 22.14% to the agricultural GDP, with striped catfish accounting for 8.54% (9406185 metric tons (MT)) of total fish production in 2022 (DoF, 2022). Along with this, Bangladesh has a competitive advantage in exporting of this fish after domestic consumption (Dhar *et al.*, 2021). Due to its soft, delicate, and white flesh, this fish has significant export expansion potential into different countries from Bangladesh (Dhar *et al.*, 2021).

However, higher lease values and better returns on investment led landowners to convert cropland into ponds (van Asseldonk, 2013), which was accused of loss of agricultural land in the pangas producing area (Ali and Haque, 2011; Anka *et al.*, 2013). Due to the traditional feeding method, uneaten feed accumulated at the pond bottom, facilitating heavy organic loads in the water, which consequently caused water quality deterioration (Anka *et al.*, 2013). Poor management of polluted water and bottom waste was very common in the aquaculture system in Bangladesh (Anka *et al.*, 2013). The rising disease burden was tackled with antibiotics, disinfectants, hormones, fertilizers and other chemicals (Heal *et al.* 2021). Moreover, farmers emphasized more on production return rather than biosecurity practices and environmental sustainability issues.

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Moreover, lack of strict monitoring of aqua waste disposal practices intensified the pollution issues. Industrial wastage increased heavy metals discharge (Hussain, 2023) in the open water system, which was deposited in soil sediment (Qaseem *et al*., 2023) and fish gills (Hoseini and Sulivany, 2024). Several risk factors, like overuse of antibiotics,incomplete treatment courses, and improper use contributed to the emergence of antibiotic resistance issues and bacterial sensitivity (Abduljabar and Naqid, 2022; Borek *et al*., 2023; Issa, 2024). So, the rapid expansion of commercial farms (Gurung *et al*., 2017; Hoque *et al*., 2021) was urging the implementation of a safe waste disposal system in this country (Haider *et al*., 2023).

Table1: Available literatures on pangas farming in Bangladesh and other Asian countries.

Aspects/Issues	Region (country)	Key Finding	Ref.
Economics	Asia (Mymensingh, BD)	Yearly production and production cost in different farming systems	Ahmed *et al*. (2010)
Socioeconomic impact	Asia (BD)	Production status and socio-economic characteristics	Belton, *et al*. (2011)
Aquaculture technique	Asia (Mymensingh, BD)	Impact of integrated aquaculture on the livelihood of resource-poor people in Bangladesh	Ahmed, N. & Thompson, S. (2011)
Land use pattern	Asia (Mymensingh, BD)	The Pangasius productivity was significantly and positively correlated with water area and dike area. About 10% of agricultural land had been converted to pangas pond.	Ali and Haque (2011)
Livelihood	Asia (Mymensingh, Cumilla, and Bogura, BD)	Training in integrated aquaculture had a significant positive impact on farm efficiency, productivity, and net income.	Murshed-E-Jahan and Pemsl (2011)
Economics	Asia (Rajshahi, BD)	Economic benefits and challenges of the pangas farming that could help in understanding the nature of the business.	Rahman et al. (2012)
Production status	Asia (Mymensingh, BD)	In the polyculture system of pond production, the yield was 6672.84 kg/ha with a stocking rate of 7377 pcs/ha.	Ali *et al*. (2016)
Disease and health management	Asia (BD)	Symptoms of diseases, financial loss of farms, and farmers' disease management activities	Faruk (2017)
Economics	Asia (Mekong Delta, Vietnam)	The result showed a positive effect on the technical efficiency of the farmers' education level and having experienced climate change impact through flooding or salinity intrusion in the past.	Nguyen *et al*. (2018)
Socioeconomic impact	Asia (BD)	Human labor negatively impacted farm output, while feed and salt have beneficial effects. Larger farms were more efficient with higher yield.	Khan et al. (2018)
Production efficiency	Asia (Mymensingh, BD)	Pangas fish farming yields higher profits in larger farms, with feed and salt positively impacting production, while human labor negatively affects efficiency.	Aktar (2018)
Aquaculture technique	Asia (Sylhet, BD)	Fish growth increases with the stocking density decreasing, and the best density was 25 fish/m³ for higher profitability.	Chowdhury (2020)
Sustainable aquaculture	Asia (Mymensingh, BD)	Sustainability assessment according to SAFA tools and ASC indicators for certification	Haque *et al*. (2021)
Fish pathology	Asia (Mekong Delta, Vietnam)	Occurrence of diseases and husbandry measures in striped catfish farms	Hoa, et al. (2021)
Marketing	Asia (BD & Viet Nam)	Heavy organic load, higher stocking rate, low water exchange, and presence of cyanobacteria (carotenoid-containing) contributed to the yellowish flesh of pangasius in Bangladesh.	Hoque *et al*., (2021)
Economics	Asia (Mymensingh, BD)	Profit efficiency was associated with better access to financial credit, extension services, and training facilities.	Khan et al., (2021)
Aquaculture technique	Asia (Anuppur, India)	Standard stocking density was 2600 fingerlings/cage.	Chaudhari, *et al*. (2022)
Economics	Asia (Mymensingh, BD)	Human labor, feed, fingerlings, and medicine/pesticide costs positively and significantly affected pangas fish production in Bangladesh. The benefit-cost ratio was 1.27, suggesting profitability. This study also mentioned that pangas farming was responsible for the agricultural land conversion and water pollution.	Haider *et al*. (2023)

BD = Bangladesh

Moreover, the unregulated growth of aquaculture in the country has ignited a contentious debate regarding the industry's capacity to enhance rural communities and alleviate poverty (Filipski & Belton, 2018), alongside environmental concerns that have tarnished the reputation of aquaculture (Menezes *et al*., 2017; Khan *et al*., 2021b). Therefore, sustainable methods of pangas farming, complying with the requirements of the world's aquaculture certification standard, should be implemented to expand the export market (Woźniacka, 2025), keep nature inact, and ensure domestic protein access.

The existing literature has primarily focused on the socio-economic status of farmers, production efficiency, value chains, farming techniques, and fish diseases (Table 1). A few studies have conducted, focusing on the environmental issues of aquaculture without sufficient depth. There is a literature gap on how commercial pangas farming impacts farmers' livelihood outcomes and the surrounding environment. Moreover, this study addresses these issues together, which might be helpful to promote a more sustainable approach to aquaculture.

Therefore, the study's goal is to gain a comprehensive understanding of the livelihood outcomes of farmers and the environmental effects of pangas farming. The first objective of this study is to determine the socioeconomic characteristics of farmers and other farming-related factors. The second one has focused on farmers' livelihood outcomes of pangas (LOP), and the third objective has aimed at identifying the factors associated with LOP after the adoption of pangas farming. In contrast, the fourth objective is to understand the negative impacts of the unplanned expansion and harmful activities of commercial pangas farming on the natural environment. Finally, the fifth one is to find out the role of commercial pangas farming on attaining sustainable development goals (SDGs) in Bangladesh.

2.METHODS

Study Area:

The multistage random sampling method was used to select study areas, and respondents were selected by the simple random sampling (SRS) method. The researchers identified six highly pangas-producing areas (Mymensingh, Cumilla, Bogura, Jashore, Barishal, and Naogaon) in Bangladesh based on the available literature and the Department of Fisheries (DoF, 2022) (Table 2). From these areas, the researchers selected five sub-districts across three districts. This study included Adamdighi along with Bogura and Muktagacha and Trishal under Mymensingh and Laksam and Nangalkot under the Cumilla district (Figure 1). Only pangas-producing sub-districts were considered in area selection, and the farmers who had at least one year of experience and were continuously involved in pangas farming were included in the study.

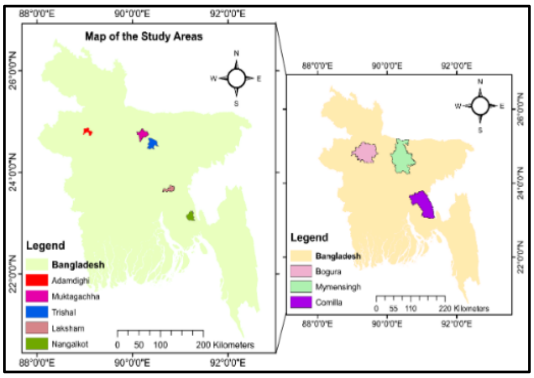

Figure 1: Map of the study areas.

Table 2: The top six pangas producing districts in Bangladesh (Source: DoF, 2022).

District name	Production (MT)	Production (%)
Mymensingh	144448	36.51
Cumilla	46756	11.82
Bogura	24501	6.19
Jashore	14593	3.69
Barishal	14608	3.69
Naogaon	11667	2.95

Data Collection Method:

This study proceeded through a mixed-methods approach. For quantitative data, a comprehensive survey with a structured questionnaire was conducted with 300 respondents from July 2023 to March 2024 from ten unions, with two unions from each sub-district, of Bangladesh. As there was no available list of pangas farmers in Bangladesh, a temporary list of farmers with farm size was made with the help of local people and the fisheries office of the respective sub-district. Approximately equal numbersof farmers were taken through the SRS method from the farmers' list of the respective unions for the quantitative survey. For qualitative data, participatory rural appraisal tools (Chambers, 1992, 2015) were used, and data collection was continued until the repetition of data from the respondents. Due to the similarity in fish culture techniques, geography, and socio-demographic features of pangas farmers, only three focus group discussions (FGDs), 12 in-depth interviews (IDIs), and twelve key informant interviews (KIIs) were conducted for data triangulation. For each FGD, 8-10 members were selected randomly from different strata of farm size from the randomly selected areas, IDIs were selected through the SRS method and the purposive method was considered for KII selection.

Data Analysis And Presentation:

Quantitative data were computed using IBM SPSS software (version 25) and MS Office 2016, and qualitative data were analyzed using key data themes. Both descriptive and inferential statistics were used for the quantitative data.

Model and Variable Description:

A three-point rating scale was used to determine the extent of livelihood outcomes through pangas farming in Bangladesh. Farmers' socioeconomic and other farming-related characteristics were represented by descriptive statistics: percentage, mean, and standard deviation. Secondly, a livelihood outcome index (LOI) was developed to evaluate the livelihood outcomes of commercial pangas farming (eq. (2)). The LOI helps to measure livelihood progress in different indicators of sustainable livelihood approach (SLA) regarding fish farming in Bangladesh (Udayakumara and Shrestha, 2011; Rahman, 2012; Amin et al., 2016; Uddin *et al.*, 2021). Thirty-two fish farming-related indicators were considered under five dimensions of SLA. Eight indicators were measured under human capital, seven under social capital, five under natural capital, seven under physical capital, and five under financial capital. Each indicator was measured with three possible responses: worsen, unchanged, and improved, and assigned scores were -1, 0, and 1, respectively. Here, the score ranges from -32 to 32, where 32 indicates the highest positive outcomes, -32 indicates the highest negative outcomes, and 0 indicates no outcomes from pangas farming. The extent of the score of outcomes was classified into three categories: poor, medium, and high.

Livelihood Outcomes of Pangas

$$(\mathrm{LOP}) = \sum_{i=1}^{i=32} \mathrm{W} \times (-1) + \mathrm{U} \times (0) + \mathrm{I} \times (1) \text{ .... } (1)$$

$$\mathrm{LOI} = \frac{\mathrm{W} \times (-1) + \mathrm{U} \times (0) + \mathrm{I} \times (1)}{\mathrm{N}} \text{ .... } (2)$$

Where, LOI = Livelihood Outcomes Index, W = number of respondents with worsening livelihood assets, U = number of respondents with unchanged livelihood assets, I = number of respondents with improved livelihood assets, and N = total number of responses.

The Pearson's correlation coefficient was computed to understand the extent of the relationship between dependable, LOP (eq. (1)), and independent variables farmers' socioeconomic & other farming-related characteristics (eq. (3)).

$$r_{xy} = \frac{\Sigma(x_1-\bar{x})(y_1-\bar{y})}{\Sigma(x_1-\bar{x})^2)(y_1-\bar{y})^2} \text{ .... } (3)$$

Where, r_{xy} = Pearson's product-moment correlation coefficient, and $\bar{x}$ *and* $\bar{y}$ = Means of the variable x and y

A multiple linear regression (MLR) model was used to measure the effect of explanatory variables (socioeconomic and other farming-related characteristics) on focus variables (LOP) (eq. (4), and normality of residuals was checked according to Kolmogorov-Smirnov (p = 0.002) and Shapiro-Wilk's (0.001) test at the significance level ($p < 0.05$). For scale reliability tests, Cronbach's alpha (> 0.7) was considered.

Regression model:

$$y_i = \beta_0 + \beta_1 xi_1 + \beta_2 xi_2 + \beta_3 xi_3 + \beta_4 xi_4 + \beta_5 xi_5 + \beta_6 xi_6 + \beta_7 xi_7 + \beta_8 xi_8 + \beta_9 xi_9 + \beta_{10} xi_{10} + \epsilon \text{ ....} (4)$$

Where, y_i = Livelihood outcomes of pangas (LOP), β_0 = Constant, $xi_1, xi_2, \ldots\ldots, xi_{10}$ = Independent variables (Age, Education, Experience in pangas farming, starting year homestead area, starting year cropland, Starting year farm size, Annual income before, Extension exposure, Knowledge of fish farming, Adoption of modern farming technology), β = co-efficient, ϵ = error term of the model. All relevant statistical tests have been done at significant levels ($P < 0.05$). In this model, unstandardized coefficient (B) was considered instead of standardized coefficient (β).

3.RESULTS

The results were represented according to the objectives of the study. The study focused on the positive and negative dimensions of pangas farming in Bangladesh. The positive dimension included objectives 1, 2, and 3, and the negative dimension included objective 4, and the fifth one was on the linkage of commercial pangas farming with the Sustainable Development Goals (SDGs).

Livehood Impact of Pangas Farming:

Farmer's Socio-Demographic Features and Farming Characteristics:

Table 3 describes the socio-demographic and farming features of pangas farmers in Bangladesh. Middle-aged farmers (49.3%) were more involved in pangas farming than young (28.3%) and old-aged (20.3%). Many of the respondents (43.3%) had secondary education and a high level of experience in fish farming (64%). The mean experience (13.27 years) and the mean schooling (10.96 years) was accompanied with the youth involvement. Most of the farmers (84.0%) had small homestead area, and 15.7% had no cropland. FGDs and IDIs reported that farmers converted their agricultural land and homestead-raised land into ponds for better profit margins from pangas rather than crop production. Moreover, cropland owners leased their lands to the medium-scale and large-scale fish farmers for pond construction, getting higher returns.

According to farm size, a larger portion (93.3%) of the farmers started their business on a small scale rather than a medium (4%) or large scale (2.7%) in the first year of pangas adoption. Before adopting pangas, their mean yearly earnings were \$196, and the largest proportion of them fell under low income (82.3%). The majority of them acquired a high level of knowledge about fish farming (65.7%) and adopted moderately modern farming technology (40%). This indicated a gradual shift in people's occupation to fish farming, with the smallest number of farms and minimal investment initially contributing to low income. Therefore, increased experience, knowledge, and modern farming technology played a significant role in promoting their business and achieving livelihood outcomes (FGDs, KIIs).

Table 3: Socio-economic and farming characteristics of pangas farmers in Bangladesh (n = 300).

Variables in categories	Frequency (n)	Percentage (%)	Mean ± SD*
Age (years)			
Young (18 - 35)	85	28.3	
Middle-aged (36 - 50)	148	49.3	42.5 ± 10.888
Old (above 50)	67	20.3	
Education (years of schooling)			
Illiterate (0)	9	3	
Primary (1 - 5)	16	5.3	
Secondary (6 - 10)	130	43.3	10.96 ± 3.598
Higher secondary (11 - 12)	67	22.3	
Higher education (> 12)	78	26	
Experience in pangas farming (years)			
Low (< 5)	37	12.3	
Medium (5 - 10)	71	23.7	13.27 ± 6.469
High (>10)	192	64	
Starting year homestead area (hectare (ha))			
Low (< 0.25)	252	84.0	
Medium (0.26 - 1)	37	12.3	0.2888 ± 0.89290
High (above 1)	11	3.7	
Starting year cropland area (ha)			
No cropland (0)	47	15.7	
Small (0.01 - 0.5)	130	43.3	
Medium (0.51 - 1)	62	20.7	1.1852 ± 3.28034
Large (< 1)	61	20.3	
Starting year farm size (ha)			
Small (<0.5)	280	93.3	
Medium (0.5 - 1)	12	4	0.2941 ± 0.50525
Large (>1)	8	2.7	
Annual income before (Dollar)			
Low (<300)	247	82.3	
Medium (301 - 600)	49	16.3	196.4775 ± 147.99082
High (>600)	4	1.3	
Extension exposure (five-point rating scale: never…… always)			
Low (<1.7)	5	1.7	
Medium (1.7 - 3.4)	135	45	3.4329 ± 0.73289
High (>3.4)	160	53.3	
Knowledge of fish farming (five-point rating scale: very unconfident…...very confident)			
Low (<1.7)	4	1.3	
Medium (1.7 - 3.4)	99	33	3.6950 ± 0.77287
High (> 3.4)	197	65.7	
Adoption of modern farming technology (possible score: 0 - 10)			
Low (<3)	68	22.7	
Medium (3 - 6)	120	40	5.62 ± 2.328
Highest adoption (> 6)	112	37.3	

Note: $ 1 = Tk 109.58 (January 2024)

Farmer's Livelihood Outcomes Through Pangas Farming:

The extent of livelihood outcomes is presented in figure 2(a). The study revealed that 65.3% of the respondents achieved high livelihood outcomes, followed by moderate (27.7%) and low (7%) outcomes. Among the five dimensions of SLA, farmers achieved the highest score on human capital (87.5%), followed by physical capital (75.7%), financial capital (70%), social capital (55.7%), and natural capital (38%) (Figure 2 (b)). Findings from FGDs and KIIs support that Pangas farming increased farmers' income, leading to improved access to education for their children. Moreover, they were taking a nutritional diet with sufficient protein and health services. They further mentioned that farmers shared their ideas and difficulties within the community, feed dealers, company agents, and fisheries officers. Thus, they solved their farming-related problems. Horticulture on the dykes ensured economic use of land but their reluctance to conserve natural resources made low scored in natural capital. Overall, income promotion improved their physical and financial assets in higher extents rather than social and natural capital.

Table 4 computed and represented the LOI and rank order of thirty-two variables of five dimensions of SLA. The findings showed that knowledge of modern farming techniques and access to farming-related information, with a score of 0.98, ranked first. The second highest score (0.97) was for income. The ability to practice modern farming techniques (0.91) ranked third, and sharing ideas with others (0.90) ranked fourth. Ability to take a nutritional and balanced diet (0.89) ranked fifth. Most farmers took informal training from various available sources, viz. successful farmers, neighbors, friends, relatives, and local representatives of input suppliers, feed dealers, and medicine sellers. Young educated farmers were prone to learning from online sources, especially from YouTube (FGDs, IDIs).

A young farmer (IDI-2) stated, "*It is very easy to get a company representative whenever I face any problem in my fishpond, and they come with their water testing kits and prescribe me to take actions to correct the condition*." Most of the farmers improved their farm size and yearly income through pangas farming (Figure 3(a, b)), which made them able to access a more nutritional and balanced diet than before. Most of the indicators scored high (>0.7), but the practice of conserving the natural gene bank of fish (-0.01) and preserving ecosystems and biodiversity (-0.04) yielded minimum and negative scores. A lower score (0.19) was also observed for the management of aquaculture pollutants, which indicated farmers negative concerns about eco-sustainability issues. FGDs and KIIs indicated that socioeconomic advancement was prevalent among pangas farmers, significantly improving their human capital and physical assets but not their natural capital. Furthermore, the lack of enforcement from regulatory agents meant that farmers were not compelled to follow environmental regulations regarding land conversion and waste disposal. Consequently, commercial farmers largely ignored environmental concerns in favor of economic gains.

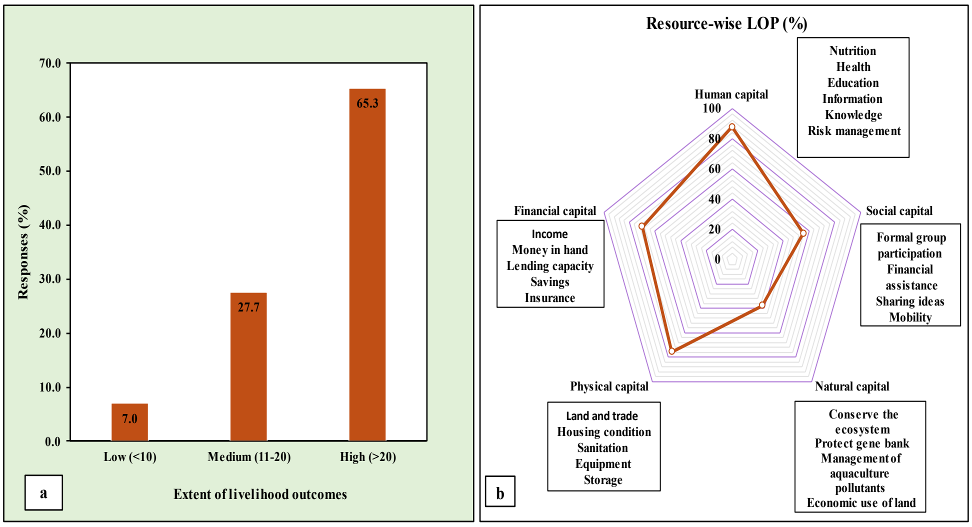

Figure 2: Livelihood outcomes of pangas farmers in Bangladesh (n = 300); (a) Extents of livelihood outcomes, (b) Resource-wise livelihood outcomes of pangas.

Table 4: Livelihood Outcomes Index (LOI) and the rank order of assessed fish farming-related indicators across five dimensions of Sustainable Livelihoods Approach (SLA) (n = 300).

Indicators of five dimensions of SLA (Score: -32 to 32)	Extent			L0I	Rank order
	Improved (n)	Unchanged (n)	Worsen (n)		
H_6. Knowledge about modern farming techniques	295	5	0	0.98	1
H_5. Ability to excess farming-related information	293	7	0	0.98	1
F_1. Income	290	10	0	0.97	2
H_7. Ability to practice modern farming techniques	274	26	0	0.91	3
S_5. Sharing ideas with others	269	31	0	0.90	4
H_1. Ability to take a nutritional and balanced diet	269	28	3	0.89	5
S_6. Sharing of aquaculture equipment with others	264	36	0	0.88	6
P_4. Possession of electronic devices	264	36	0	0.88	6
N_3. Maintenance capacity of artificial fish bank	264	36	0	0.88	6
P_6. Farm equipment	261	39	0	0.87	7
P_5. Sanitation facilities	256	44	0	0.85	8
H_4. Hygiene and sanitation practices	256	44	0	0.85	8

N_5. Economic use of land	261	34	5	0.85	8
P_3. Housing condition	250	50	0	0.83	9
H_8. Capacity to face risks and vulnerabilities	245	54	1	0.81	10
F_3. Money lending capacity	249	45	6	0.81	10
F_2. Liquid money in hand	249	45	6	0.81	10
H_3. Aspiration of higher education for children	237	63	0	0.79	11
H_2 Access to modern health services	234	66	0	0.78	12
P_7. Storage capacity	236	61	3	0.78	12
F_4. Savings	226	71	3	0.74	13
S_4. Social acceptance	213	85	2	0.70	14
P_1. Ownership of land	178	112	10	0.56	15
P_2. Business and commercial spaces	162	133	5	0.52	16
S_7. Mobility	144	155	1	0.48	17
S_2.Willingness of financial assistance to others	108	192	0	0.36	18
S_1. Formal group affiliation	108	179	13	0.32	19
S_3. Participation, social, and national rituals	103	184	13	0.30	20
F_5. Ownership of insurance	90	195	15	0.25	21
N_4. Management of aquaculture pollutants	167	23	110	0.19	22
N_2. Practices to conserve the gene bank of fish	48	200	52	-0.01	23
N_1. Practices to conserve ecosystem/biodiversity	41	205	54	-0.04	24

Note: H = human capital, F = financial capital, S = social capital, N = natural capital, P = physical capital, improved = 1, unchanged = 0 and worsen = -1 [possible scores against each statement]; LOI = livelihood outcomes index.

Correlation Between Farmer’s Characteristics and LOP of Pangas Farmers:

Table 5 represents a summary of the relationship between farmers’ characteristics (explanatory variables) and livelihood outcomes (focus variables). The results showed a significant relationship between all the explanatory variables and the focus variable. A farmer's experience, knowledge of fish farming, and adoption of modern farming technology were strongly correlated (r > 6) to LOP. On the other hand, a panga farmer’s age, education, starting year homestead area, starting year cropland, starting year farm size, annual income before, and exposure to extension services exhibited moderate correlation (r > 2).

Table 5: Correlation of farmer’s characteristics and livelihood outcomes of pangas (LOP) (n = 300)

Farmer’s characteristics	Correlation coefficients (*r*)	Sig. level	
		0.05	0.01
Age	-0.269**	0.196	0.257
Education	0.303**		
Experience in pangas farming	0.670**		
Starting year homestead area	- 0.205**		
Starting year cropland area	0.270**		
Starting year farm size	-0.236**		
Annual income before	-0.242**		
Extension exposure	-0.372**		
Knowledge of fish farming	0.638**		
Adoption of modern farming technology	0.627**		

**Correlation is significant at the 0.01 level (two-tailed), n = 300, *df* = 298.

Influencing Factors of Farmer’s Livelihood Outcomes of Pangas (Lop):

We conducted a multiple linear regression analysis to identify the key factors influencing livelihood outcome performance (LOP) and assess their statistical significance. The results (Table 6) showed that five of the ten explanatory variables were significant ($p < 0.05$), and the adjusted R^2 value was 0.645. This meant that the explanatory variables explained about 64.5% of the LOP. The data did not have autocorrelation, as shown by the Durbin-Watson value of 1.837. Also, the variance inflation factor (VIF) was less than 6, which meant that the independent variables did not have multicollinearity. The analysis showed that a farmer’s age (B = -0.052, t = -2.134, $p < 0.05$) had a negative impact on LOP. The farmer’s education (B = 0.130, t = 2.046, $p < 0.05$), experience (B = 0.431, t = 9.082, $p < 0.01$), knowledge of fish farming (B = 2.858, t = 7.410, $p < 0.01$), and adoption of modern farming technology (B = 0.637, t = 5.205, $p < 0.01$) have a positive effect on attaining livelihood outcomes. The remaining five explanatory variables were statistically insignificant. Among these, starting annual income might have a negative impact (B = -3.244, t = -1.653, $p < 0.10$) on the livelihood outcomes of pangas.

However, the initial homestead area, farm size, and extension exposure all had negative-insignificant coefficients had a negative impact on LOP. According to IDIs and FGDs, most of the farmers converted their raised land to lowland fishponds for better returns, resulting in an increase in LOP with a decrease in their starting-year homestead area and croplands. The qualitative study also stated that some of the farmers got their advice from feed dealers who weren’t experts in fisheries and had difficulties communicating with the government extension agents.

Stepwise Multiple Regression:

We computed stepwise multiple regression to assess each explanatory variable’s individual contribution to the livelihood outcomes of pangas farming (Table 7). The model was made up of four explanatory variables: the farmer’s experience, knowledge, use of adaptive farming technology, and age. These four independent variables (R^2 = 64.7) explained about 65% of the livelihood outcomes of pangas. Experience in pangas farming as the first variable entered the model, able to explain the maximum variability of the model (44.7). The second variable, knowledge of fish farming, explained only 15.9%; the third one, adoption of modern farming technology, described 27%; and finally, the fourth variable, age, entered the model, explaining only 9% of the variation of the focus variable, LO

Table 6: Multiple linear regression to understand the relationship between farmers' characteristics and livelihood outcomes (n = 300).

Farmer's characteristics	Unstandardized coefficients		t	sig. B
	B	Std. Error		
Constant				0.002
Age	-0.052*	0.024	-2.134	0.034
Education	0.130*	0.064	2.046	0.042
Experience in pangas farming	0.431**	0.047	9.082	0.000
Starting year homestead area	-0.211	0.367	-0.577	0.565
Starting year cropland area	0.191	0.161	1.189	0.235
Starting year farm size	-1.135	0.776	-1.463	0.144
Annual income before	-3.244	1.963	-1.653	0.100
Extension exposure	-0.377	0.361	-1.043	0.298
Knowledge of fish farming	2.858**	0.386	7.410	0.000
Adoption of modern farming technology	0.637**	0.122	5.205	0.000

Significant, if $p < 0.05$, confidence level = 95%, $F = 55.245$, df (degrees of freedom) = 299; *Regression is significant at the 0.05 level and **Regression is significant at the 0.01 level.

Table 7: Summary of the Stepwise Multiple Regression (n = 300).

Model	Variable entered	R^2	Adjusted R^2	Variation explained	Sig. level
1.Constant + xi_3	Experience in pangas farming (xi_3)	0.449	0.447	44.7	0.000
2. Constant + xi_3 + xi_9	Knowledge of fish farming (xi_9)	0.609	0.606	15.9	0.000
3. Constant + xi_3 + xi_9 + xi_{10}	Adoption of modern farming technology (xi_{10})	0.637	0.633	27	0.000
4. Constant + xi_3 + xi_9 + xi_{10} + Xi_1	Age (Xi_1)	0.647	0.642	9	0.000

Raising Economic Opportunities of Pangas Farming:

Overtime, both farm size and income of farmers have increased, leading to better livelihood outcomes (Figure 3(a, b)). Fish farming provided opportunities to be involved in various primary and secondary occupations alongside farming activities (Figure 3(c)). Only one-third (33%) engaged solely in fish farming, followed by 23% in crop production, 29% in fish-related business, 10% in service, and 4% in other businesses (Figure 3(c)). In addition to pangas farming, most farmers expanded their income-earning scopes by engaging in diversified employment opportunities..

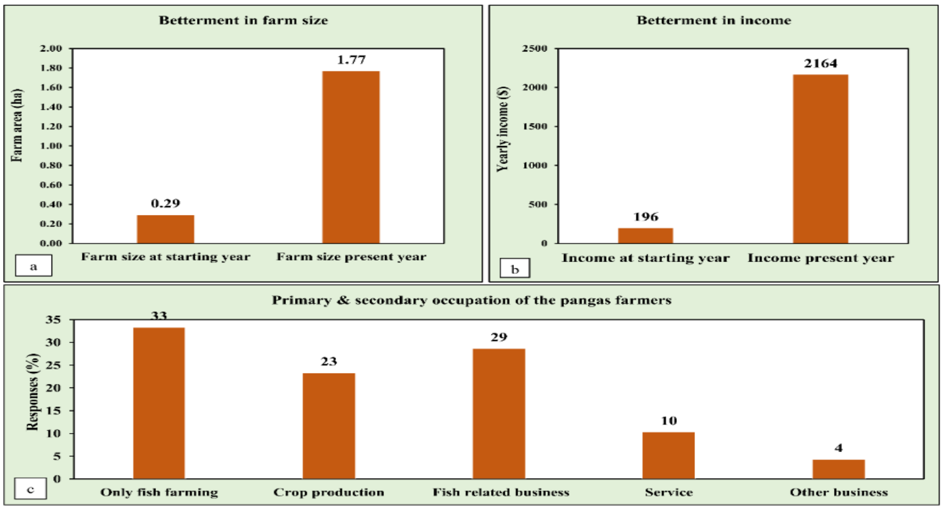

Figure 3: Impact of pangas adoption on the economic well-being of fish farmers in Bangladesh (n = 300); a) Betterment in farm size, b) Betterment in income, c) Scope of primary and secondary occupations.

A local political agent (KII-3) stated, "The economy of Trishal heavily relies on pangas farming, and this has significantly increased job security for the local youth." He also mentioned, "Pangas farming contributed to the expansion of the hatchery business in Adamdighi." A pioneer pangas introducer in Adamdighi (KII-7) asserted, "We sell fry and fingerlings in different corners of Bangladesh as well as neighbouring provinces of India. Due to huge demand, this industry attracted people to switch their previous occupations and establish their own fish business, promoting their economy." KIIs claimed that pangas farming has become popular because of simple farming techniques, higher consumer demand, higher growth of fish, and an effective and quick return on investment.

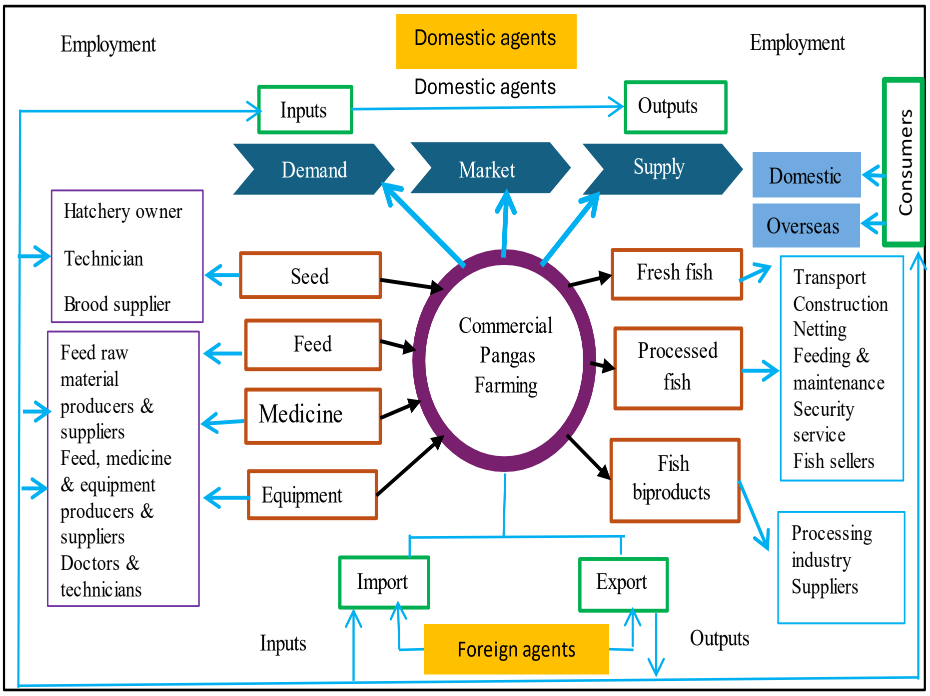

Figure 4: Diagram of employment linkages of pangas farming in Bangladesh (Field study, 2022-2023).

Moreover, favourable soil texture, temperature, availability of improved variants, and information made this business more popular among the entrepreneurs.

The commercial pangas farming process has developed and facilitated both upward and backward linkage industries, as represented in Figure 4. The backward linkage industries, such as fish seed, feed, equipment, medicines, chemicals, and fertilizer, promoted employment opportunities. Furthermore, fish harvesting, transporting, marketing, processing, and exporting have expanded the upward linkages to foster income-generating activities through fish farming in Bangladesh

Environmental Impact of Farming Interventions:

Land Structure Modification Due To Commercial Scale of Fish Farming:

There was a negative impact on the surrounding environment due to the farming activities in the study areas. Land structure modifications, particularly the shifting of cropland into closed waterbodies, decreased the area under crop production. Moreover, raising dikes in ponds resulted in the formation of waterlogged areas during the rainy season, which negatively impacted the cultivation process. The accumulation of organic matter and the intrusion of aqua chemicals residue in the open water bodies from fish farms negatively impacted the ecosystem, underscoring the need for sustainable aquaculture practices.

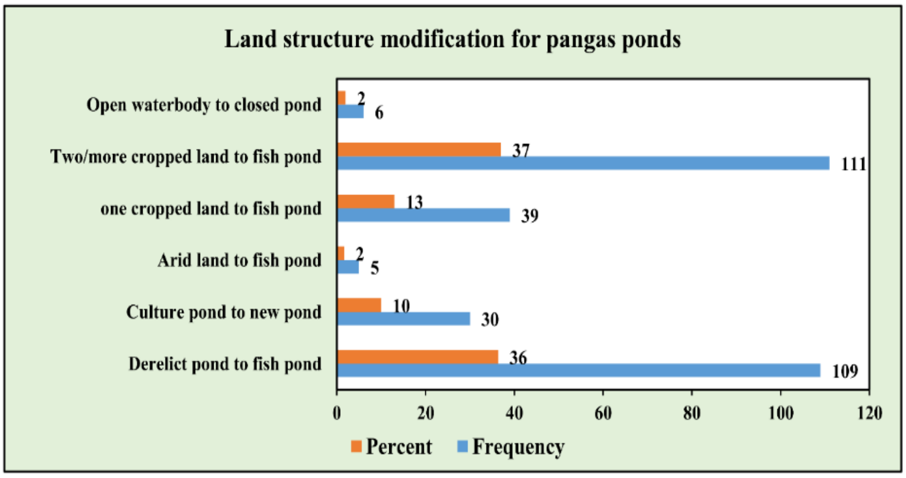

Figure 5: Conversion of different types of lands into closed water pangas farms in Bangladesh (n = 300

The area of closed inland water increased tremendously in the last two decades (DoF, 2022). In this study, the closed pond originated from various land types (Figure 5). In the study areas, 37% constructed their ponds on two or more cropped agricultural lands, 36% reconstructed their derelict ponds, 13% converted single-cropped agricultural lands to aquaculture, and 10% used culturable ponds for aquaculture of pangas. A small percentage of respondents (2%) stated that they built their ponds on arid land, while 2% converted open water bodies into closed ponds. FGDs claimed that constructed embankments in the floodplains sometimes caused waterlogging in the croplands. Furthermore, this hampered aquatic animals' navigation processes during the breeding season.

Intrusion of Pollutants in Natural Water:

Farmers' pollution management strategies in Bangladesh depended on their local resources, including natural water bodies, agricultural practices, and personal reservoirs, as shown in Figure 6. About half of the respondents (52%) discharged their chemically mixed polluted water in open water bodies, 27% reused it for irrigation purposes, and 21% discharged it in their own unit (Figure 6(a)). To remove the organic load, 49% of farmers disposed of bottom sludge in nearby rivers and canals; 35% reused it as organic fertilizer; and 15% utilized it in landfills for developing different infrastructure (Figure 6(b)). Figure 6(c) showed how often polluted water was released: 6 to 10 times (39%), then 1 to 5 times (24%), 11 to 15 times (22%), 15 to 20 times (7%), more than 20 times (6%), and no release (3%). Farmers used to dry their ponds at various intervals to remove bottom sludge. Many farmers (47%) removed bottom sludge annually, followed by three yearly (35%), two yearly (17%), and no discharge (1%), as shown in figure 6 (d).

Farmers frequently faced problems such as gas bubble formation, excessive organic load in the pond bottom resulting in fish suffocation, and eutrophication. To improve their pond environment, they had to exchange heavily organic-loaded water. Most of the farmers did not have their own discharge units, so they relied on natural water bodies to release the pollutants. Consequently, the growth of pangas farms in the study areas increased the amount of heavy organic matter in the open water canals and riverbeds. This made it harder to find fish in open water, which in turn made it difficult for the poor to eat enough protein (FGDs)

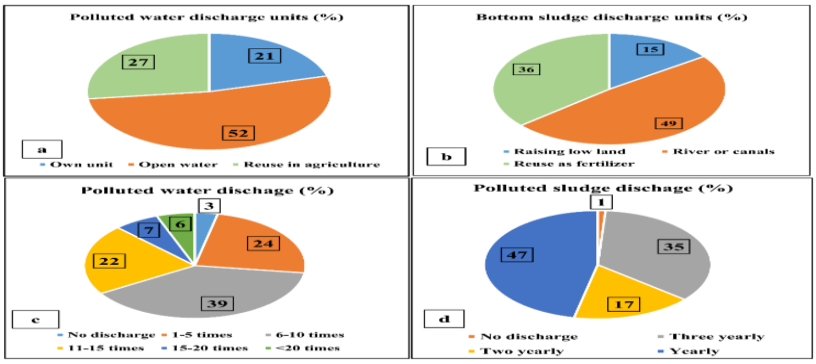

Figure 6: Pollutant management practices of pangas farmers in Bangladesh (n = 300); a) Discharge units of polluted water, b) Discharge units of bottom sludge, c) Frequencies of polluted water discharge, d) Frequencies of bottom sludge discharge.

A farmer (IDI-7) from Trishal, Mymensingh, expressed his concern about the environmental deterioration stemming from waste discharge in the nearby 'Sutia' river:

Pangas requires a substantial quantity of additional feed. Most of the farmers in our area use home-formulated low-cost pelleted feed crushed from nearby feed mills, rather than commercial floating feed. Sometimes, a big amount of the feed sinks to the bottom of the pond, which causes harmful gases and eutrophication issues. This exacerbates changes in the water parameters, leading to fish floating on the surface. This situation necessitates the application of various aquatic chemicals to correct water parameters. For quick recovery, we exchange some water and discharge the polluted water into this river. Consequently, the rivers have lost their fish and other animals.

KIIs also said that pangas farms were characterized by having a high density of fish, feeding them with low-quality food, using traditional feeding methods, and not managing the farms well. They also added that this lost bottom-settling feed portion and fish excreta were the main causes of excessive gas formation. Water quality deterioration and huge biodiversity loss in 'Roktodoho Beel' from farm discharges were claimed by IDIs from Adamdighi, Bogura.

Accumulation of Aqua Chemicals in Nature:

Farmers used diverse types of insecticides to kill the unwanted insects and microorganisms in the water before stocking. They collected the medicines from the local feed dealer and veterinary/aquatic medicine shops. Most of them consulted with the company agent in cases of chemical or medicine selection. Medicine sellers encouraged farmers to experiment with various medicines and chemicals to improve their pond conditions, even though they struggled to find the right solution to correct the environment. Farmers used fenitrothion (Sumithion) as a killer of mini-food competitors, especially insects, in pond ecosystems; carbofuran for nematode killer; ivermectin for *Arugulus sp.* killer; and deltamethrin for insect killer. Furthermore, farmers used various veterinary antibiotics, such as tetracycline, fluoroquinolones, sulfonamides, phenicol, gentamicin, amoxicillin, and aminoglycoside-like agents to

combat fish diseases. Farmers discharged this medicine-mixed water into nearby rivers or canals. Therefore, this polluted water contributed significantly to the depletion of open-water biodiversity. A 65-year-old farmer (IDI-4) stated:

We have seen the canals, ditches and rivers in abundance with a vast number of fishes, snails, snakes, turtles, crabs, shrimps, and aquatic weeds. The poor villagers used to catch fish and sell them in the local market. These fishes not only contributed to their income but also met up their family's protein demand. Aquaculture waste has left these waterways polluted and fishless; consequently, the marginalized people are facing challenges to access protein due to the scarcity of fish in these water bodies

SUSTAINIBLE AQUACULTURE FOR SUSTAINABLE LIVELIHOOD OUTCOMES

Sustainable aquaculture focuses on economic, social, and environmental sustainability practices. In this study, economic sustainability was assessed by farmers' progress in physical (75.7%), financial (70%), and human (87.5%) capitals; notable progress was observed in these areas. In the case of social capital (55.7%), moderate improvements occurred, explaining social sustainability. However, the poorest progress in natural capital indicated the farmer's lowest concern about environmental sustainability issues (Figure. 7). Among five indicators, biodiversity conservation practices scored the lowest value (-0.04), which ranked 24 among 32 indicators of LOP. The protection of the natural gene bank received the second lowest score (-0.01), ranking 23, indicating a retrogression in this indicator. Farm pollutant management showed negligible progress, with a score of just 0.19. These three indicators in natural capital raised a question regarding environmental sustainability practices through pangas farming adoption in Bangladesh (Table 4, Figure 7).

Table 8: Role of pangas farming in attaining Sustainable Development Goals (SDGs).

SDGs	Relationship with the study	Contributions
SDG 1: Zero poverty	The study addresses the livelihood impacts of pangas farming. particularly its role in creating scope for part-time and full-time jobs for unemployed labour.	Improves household livelihoods, especially for rural people, through increased product diversification and overseas market access of pangas. Enhances employment scope in rural regions, raising income levels to diminish poverty rates.
SDG 2: Zero Hunger	Addresses the significance of pangas farming in enhancing food security through the increase of production.	Improves quality protein access from pangas consumption. Promotes engagement in the value chain of fish pangas production to income promotion.
SDG 3: Good Health and Well-being	Considers the health improvement from nutrition-rich fish consumption and sales.	Enhances health outcomes by supplying a substantial quantity of protein and vital nutrients. Improves purchasing power, promoting access to fish.
SDG 8: Decent Work and Economic Growth	Examines the economic advantages of pangas aquaculture and its influence on rural economies.	Facilitates sustainable economic development through job creation and the enhancement of local economies. Promotes entrepreneurship and investment in aquaculture.
SDG 12: Responsible Consumption and Production	Focuses on sustainable agricultural practices and their environmental impacts.	Advocates for sustainable production practices that reduce environmental harm. Promotes the effective utilization of resources and waste management in pangas farming.
SDG 14: Life Below Water	Examines the ecological impacts of pangas aquaculture on aquatic ecosystems.	Aims to alleviate adverse effects on water quality and biodiversity. Promotes sustainable aquaculture practices to save water resources.
SDG 15: Life on Land	Investigates the extensive environmental adverse effects of farm pollutants, encompassing land structure modification and biodiversity degradation.	Strengthening strategical implementation to mitigate habitat degradation. Emphasizes on the necessity for sustainable land management of farm effluents. Fosters the conservation of terrestrial and freshwater habitats.
SDG 17: Partnerships for the Goals	Emphasizes the significance of stakeholder participation for sustainable development.	Enhances collaborations among fish farmers, related researchers, policymakers, and international organizations to achieve common targets. Facilitates knowledge transfer and capacity development for sustainable aquaculture.

4.DISCUSSION

We conducted this study on 300 pangas farmers from a wide range of geographical locations in Bangladesh to investigate their livelihood changes and the environmental impact of commercial farming. The primary objectives of the study were to find out the impact factors of farmers' livelihood outcomes and address the adverse effects of farming activities on the surrounding environment. A significant portion of farmers gained high (65.3%) to moderate (27.7%) outcomes, indicating the positive impact of shifting to pangas farming. Van Asseldonk (2013) referred to pangas as an internal boom crop and found rapid agrarian shifts to pangas farming leading to better livelihood outcomes in Bangladesh. Some findings on the socioeconomic status of fish farmers also suggested livelihood improvement (Sarwar *et al*., 2016; Adhikary *et al*., 2018; Sheheli *et al*., 2021; Khanom *et al*., 2022; Al Mahadi *et al*., 2022). This study found a strong correlation between explanatory variables, such as the farmer's experience, knowledge, and adoption of modern farming techniques, and the focus variable, LOP, suggesting that these factors significantly contributed to the positive change in the livelihood of pangas producers. Sheheli *et al*. (2021) identified that the farmer's education, knowledge, farm size, and annual income were significantly correlated with the livelihood status of fishermen. According to a study by Tasnoova *et al*. (2017), pangasiid catfish aquaculture had greatly improved the social and economic situations of many people involved, such as hatchery owners, nursery pond managers, fingerling sellers, pangasiid growers, and fish vendors. Existing literature has discussed only the livelihood status of fish farmers without conducting an impact assessment. This study also suggested that new farmers with minimal resources gradually improved their livelihood over time. In this study, the farmer's age significantly negatively impacted LOP, whereas the farmer's education, experience, knowledge, and adoption of modern farming techniques positively influenced LOP. Alternative results, claimed by Adams *et al*. (2021), that the age of the farmers and their access to extension services positively impacted the adoption of technology. In this study, most of the farmers were middle-aged (49.3%) and young (28.3%), with an average age of 42.57 years, indicating that young people were more interested in pangas farming and doing better than the old. Another study on fish farmers by Rajan *et al*. (2013) reported that the majority were young. Most of the farmers achieved the secondary level of education, indicating that it was enough to face the technical challenges of fish farming and gain better livelihood outcomes. Uddin *et al*. (2021a) explained that farmers' education increased as farm constraints decreased. Another study by Rajan *et al*. (2013) found that higher education showed a positive association with farmers knowledge. Young and educated farmers, according to FGDs, managed their farms more effectively and gathered information from both online and offline sources. KIIs also claimed that at least secondary education was needed to run the farm effectively. Therefore, livelihood outcomes decreased as farmers ages increased and education impacted vice versa.

Moreover, farmers' experience showed a positive, significant impact on gaining higher livelihood outcomes. Rajan *et al*. (2013) claimed that the experience of fish farmers had a positive association with knowledge levels. FGDs and KIIs stated that farmers with more experience had a higher risk orientation, facilitating higher livelihood outcomes. Additionally, LOP increased with the level of farmers' knowledge. This suggested that farmers with greater knowledge were more adept at managing production risks and achieving higher returns from their farms. The adoption of modern farming technology also positively influenced the achievement of higher outcomes. Access to technology information aimed to improve farmers' efficiency and increase their net income, thereby enhancing their livelihoods (Murshed-E-Jahan and Pemsl, 2011; Kumar *et al*., 2018). Farmers usually chose technologies that would be more cost-effective and easier to manage (Ngo *et al*., 2019; Kumar *et al*., 2018), and these technologies also bestowed benefits to the well-being of small-scale farmers (Adams *et al*., 2021). Embracing modern and appropriate technologies not only decreased prices but also led to poverty alleviation, enhanced nutritional standards, increased employment opportunities, and improved overall welfare for individuals (Mango and Kariuki, 2015). Additionally, FGDs and KIIs asserted that small-scale farmers became more skilled with their experience gathering, adopting modern farming technology, and sharing their knowledge with various stockholders, subsequently boosting their livelihood outcomes. Furthermore, initial farm size and starting income negatively influenced the ability to achieve a higher LOP, indicating small-scale farmers improved their livelihoods more than medium and large-scale farmers. Uddin *et al*. (2021) found that constraints of farming increased with the farm area increasing. Moreover, small-scale farmers were more concerned about reducing farm risk; thus, they raised income and food security (Murshed-E-Jahan and Pemsl, 2011). In this study, about 93% of the pangas farmers had small farms at the start; however, over time they increased their farm size and achieved higher outcomes. Pangas farming inflated business scope both for the farmers and the local people due to its diverse linkage with various businesses (van Asseldonk, 2013). Aquaculture was playing a crucial role in Bangladesh by creating job opportunities and boosting foreign exchange earnings (Shamsuzzaman *et al*., 2020). Farming this fish expanded both full-time and part-time on-farm as well as non-farm employment opportunities for local people (Faruque, 2007; Latwal and Srivastava, 2016). Fish farming created opportunities for primary and secondary income sources, thus alleviating poverty and improving livelihood (Wuyep and Rampedi, 2018). This sector generated more employment than other activities (Meenakshi and Srivastava, 2016). Moreover, KIIs and FGDs also claimed that pangas farming changed the local economy, creating jobs for the unemployed people in the study areas.

On the other side, people converted huge amounts of land in the farming-intensified areas (Figure 5). Most of them converted their raised lands to lowland fishponds for better return (Zaman, 2017). Along with this issue, the lowest score of natural capital (1.99) implied that farmers were less concerned about environmental eco-sustainability issues (Table 4). Moreover, raised dikes created barriers to water passage and caused waterlogging, which reduced crop production in pangas-producing areas. Beside this, frequent water exchange allowed toxic organic and inorganic components to enter the open water ecosystem. Polluted water discharge enhanced the entrance of organophosphorus components, killing the fish embryos, larvae, and adults, which impacted negatively in fish organs like fewer eggs being fertilized, eggs being malformed, induced larval mortality, and morphological aberration (Rahman *et al*., 2020); changes to the gills, liver, kidneys, and testes (Benli and Özkul, 2010); and fewer hemoglobin and red blood cells (Hossain *et al*., 2015). The breeding performance of stinging catfish was also hampered by the residual effect of sumithion (Das *et al*., 2016). Therefore, we can hypothesize that the discharge of water containing agrochemicals damages natural ecosystems both directly and indirectly. Heavy metal accumulation, eutrophication, food poisoning, contamination of infectious diseases, and loss of valuable organisms were also intensified by waste discharge from commercial aquaculture units (Ojewole *et al*., 2024). The quick growth of the aquaculture sector (Drizo, 2023) generated environmental dangers and created questions about water pollution originating from aquaculture output facilities and pollutant discharge. Aquaculture effluent consisted mostly of leftover feed, silt particles, metabolic waste from the farmed fish, and hazardous aqua chemicals (Ojewole *et al*., 2024). The poor management techniques, such as excessive feeding, poor feed selections, crowding, wrong species selection, antibiotic abuse, and improper wastewater discharge, badly contaminated watersheds and squandered precious resources (Li *et al*., 2024). Aquaculture activities could thus generate more antibiotic residues, antibiotic-resistant bacteria, persistent organic pollutants, and heavy metals in produced finfish and shellfish (Sapkota, 2008).

This agrarian transition from agriculture to pangas farming in the study areas raised a key concern about the waste management systems, which might hamper reaching the benefits of farming to all stockholders. Farmers' registration, farm monitoring system and adaptive farming technology should be established to ensure environmental sustainability and social integrity. Moreover, reusing and recycling techniques can minimize the farm waste. Otherwise, one-sided beneficiary groups may tarnish the free protein access from common sharing resources and affect the livelihood of fishermen. To get the maximum benefit with the least compensation of nature, policy have to be put in action along with proper training, field-based demonstration, formal inspection, and establishment of pangas farmers' community discharge units for reuse and recycling of waste (FGDs, IDIs). Modern environmentally friendly farming techniques can help to lower unfavourable effects on the surroundings (Araujo *et al*., 2022). Several models—constructed wetland treatment model (CWT), ecological ditch treatment model (EDTA), integrated multi-trophic aquaculture model (IMTA), and recirculating aquaculture model (RAS)—are suggested for modern aquaculture to lower the pollution.

Finally, this study suggests a significant improvement in the farmers' living standards, along with creating scope for job opportunities in this multi-faceted agro-based industry in Bangladesh. Food and nutrition security and national macroeconomic stability depend on fisheries (Sunny *et al*., 2021), which are related to SDG 1: no poverty; SDG 2: zero hunger; and SDG 14: life below water. Furthermore, achieving SDG-14 requires responsible aquaculture (FAO, 2023). Bangladesh meets its own protein needs with pangas (DoF, 2023) as a major fish protein source. She can also contribute to the global food security (SDG-1, 2.3) by supplying high-quality fish and fisheries products on the international market, abiding by the global GAP (Good Aquaculture Practices) and ASC (Aquaculture Stewardship Council) certification standards (Haque, 2021). But minimal emphasis on aquaculture sustainability and product standards is hampering the attainment of the SDGs (Goals 12, 14, 15, and 17) in Bangladesh.

This cross-sectional study has some limitations in assessing the time being effects of pangas farming on attaining LOP. A longitudinal study might be suggested to get better interpretations. Future research can be conducted to reveal the underlying causes of farmers' constraints to adopting more sustainable aquaculture practices in Bangladesh.

CONCLUSION

The study showed a favourable score on human capital, physical capital, social capital, and financial capital but also expressed worries about its environmental consequences, providing the lowest score on the natural capital indicators. Positive outcomes on the indicators of the four capitals indicated that the farmer had acquired skills, physical assets, social responsibility, and financial efficiency. Therefore, pangas farming has positively impacted four aspects of SLA, except for natural capitals. From the interviews, it was understood that the respondents were more concerned about profit maximization than the liabilities of natural ecosystems. The farmer's education level, experience, knowledge, and adoption of modern farming technology significantly contributed to promote their better livelihood outcomes. Quite the reverse, the respondents converted agricultural lands and discharged pollutants into the environment, raising questions about the sustainability of aquaculture practices in pangas farms in Bangladesh. So, to get the maximum benefits of pangas production in Bangladesh, farmers need to adopt modern feeding methods to reduce feed loss and follow the biosecurity practices to reduce the hazards. Additionally, governmental initiatives are required for farmer registration and field demonstration with laboratory support to ensure sustainable pangas farming. This study only focuses on farmers' perceptions and practices; experimental findings are still missing in the study. Future research may be conducted to assess the residual effect of aqua drugs on human health.

CONFLICT OF INTEREST:

Authors have no conflict of interest.

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AUTHORS' CONTRIBUTIONS:

Khaleda Nasrin, as primary author, implemented data collection, conceptualized the study, analysed the data, and wrote the manuscript. The study presented here is part of the primary author's PhD degree. As a supervisor, Md. Yeamin Hossain designed the study's methodology, conceptualized the work, analysed the data, and reviewed and edited the writing. We further declare that all writers have contributed, checked over, and approved the manuscript.

Notes:

1. The Pearson's product-moment correlation coefficient, shortly known as Pearson's correlation coefficient (Puth *et al*., 2014), is used to measure the linear relationship between dependent and independent variables for interval or ratio data. In this study, the dependent variable was index data, and the independent variables were either numeric or Likert scale-like data. So, linear relationships were considered among the explanatory and focus variables. The extent of the relationship ranges from strong negative (-1) to strong positive (1).
2. Cronbach's alpha coefficient (Robert, 2005) is typically utilized to assess the reliability of multi-item scales. For the scale reliability test, the value of Cronbach's alpha is computed by IBM SPSS software.
3. In this study, multiple linear regression analysis was conducted to identify the factors and their significant impact in predicting the dependent variable, livelihood outcomes of pangas (LOP). The model residuals normality test was checked according to the Kolmogorov-Smirnov and Shapiro-Wilk tests at a 5% significance level.
4. Autocorrelation among dependent variables was checked by the Durbin-Watson test. Data normality was also verified by the Variance Inflation Factor (VIF) value (the rule of thumb indicates that a VIF below 10 signifies the absence of multicollinearity and the acceptance range of the Durbin-Watson value is 1.5 to 2.5).

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