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Assessing the Abundance and Diversity of Snails in Freshwater Ecosystems in Relation to Water Quality and Weather Parameters

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ABSTRACT

Bangladesh’s rich aquatic biodiversity and favorable agroclimatic conditions boosted aquaculture production to an extent. However, despite its potential, aquaculture output falls short of expectations due to its reliance solely on finfish culture. There is significant untapped potential in cultivating other aquatic species in Bangladesh, such as snails, mussels, etc. This study examined the culture potential of freshwater snails by assessing their natural abundance in three different pond systems in relation to various environmental parameters. This investigation was carried out for six months at aquaculture, non-aquaculture and derelict ponds by using quadrat sampling methods. Five species of freshwater snails and one species of mussel were identified from the selected ponds. A multiple linear regression analysis was conducted to assess the changes in snail abundance in relation to various water quality and weather parameters, using the number of identified snails as the independent variable. The model obtained R^2 values of 0.934, 0.741, and 0.788 for the aquaculture, non-aquaculture, and derelict ponds, respectively. The significant independent variables influencing snail abundance varied across pond types: In aquaculture ponds, the key factors were water depth, water transparency, and rainfall; In non-aquaculture ponds, they were air temperature, pH, water temperature, and water depth; and in derelict ponds, they were water temperature, water depth, air temperature, and rainfall. These findings could facilitate the integration of snail culture into existing aquaculture practices, such as Integrated Multi-Trophic aquaculture (IMTA), to boost food production, economic growth, and ecosystem health.

INTRODUCTION

Aquaculture is one of the world's most rapidly expanding food producing sectors **(Azra *et al.* 2021)**. It is a key component of the global food supply, having superseded fisheries output as the primary source of aquatic foods **(Davis *et al.*, 2021)**. Aquaculture is regarded as one of the most sustainable solutions for achieving and enhancing food security **(Barange *et al.*, 2018, Sarà *et al.*, 2022)**, as well as producing high-quality animal protein in the food supply chain **(Mangano *et al.*, 2022)**. Bangladesh, with its rich aquatic biodiversity and favorable resources and agroclimatic conditions, is regarded as

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one of the most suitable countries in the world for freshwater aquaculture. Despite its potential resources, aquaculture production in Bangladesh has yet to meet expectations. Given the immense potentials, Bangladesh has become a major fish-producing country globally, currently ranking fifth. However, expanding into non-conventional aquaculture holds even greater promise, offering the opportunity to significantly boost overall aquaculture production **(Alam & Haque, 2021; Haque *et al.*, 2021a; Haque *et al.*, 2021b)**. In Bangladesh, finfish production is the cornerstone of the aquaculture industry. The other fish producing nations are demonstrating the prospects for culture of other aquatic animals, such as molluscs, mussels, snails, oysters, etc.

In 2020, the global production of other farmed aquatic animals other than finfish reached 17.7 million MT of molluscs (US$ 29.8 billion) mostly bivalves, 11.2 million MT of crustaceans (USD 81.5 billion), 525,000 MT of aquatic invertebrates (US$ 2.5 billion) and 537,000 MT of semi-aquatic species including turtles and frogs (US$ 5 billion) (FAO, 2022). Asia, particularly China, is the dominant producer, contributing a whopping 85% of the marine bivalve production in the world. In contrast, production in other continents, such as Europe, has either stabilized or declined in recent decades. In Southeast Asia, Thailand, Malaysia, the Philippines and some of the countries are actively involved in marine mollusc farming **(Wijsman *et al.*, 2019)**. The Philippines, with its vast coastline and abundant coastal waters, values molluscs as valuable farmed aquatic animals. In 2020, production from mussels and oysters was valued at almost USD 26 million **(Lebata-Ramos, 2023)**.

In Bangladesh, 362 species of mollusc have been identified, of which, 336 species are marine, and 26 species are from freshwater sources **(Anisuzzaman *et al.*, 2016)**. Gastropods and bivalves are the two largest and most prevalent classes of molluscs, having a wide variety of marine and freshwater species. Snails, slugs, and limpets are gastropods, whereas mussels, clams, oysters, and scallops are bivalves **(Mason *et al.*, 2014)**. Approximately, there are about 5,000 species of freshwater snails found in lakes, ponds, and streams around the world **(Soldánová, 2013)**. Freshwater mussels encompass over 900 species worldwide, with the highest diversity found in Southeast Asia and North America. Global demand for the preferred high-protein molluscan meat is increasing. Freshwater molluscs such as snails and mussels are an economically important group of animals and a food source which contain high protein and negligible amount of fat content. Although there is no evidence for when and where human being first started to consume snails, it is known that eating snail meat transcends back to prehistoric times **(Lubell, 2004)**. Snails are popular food items in many developed as well as developing countries in the world. In Italy, the production and consumption of snails almost doubled between 1995 and 2010, with a 2013 annual sales value of about Euro 265 million **(Baghele, 2021)**. It is somewhat surprising that people from diverse cultures globally still incorporate various types of snails into their diets. In Southeast Asia, fish and molluscs provide over 50% of all consumed protein.

Snail cultivation remains largely unexplored in Bangladesh and is not commonly consumed due to religious concerns **(Nath *et al.*, 2008)**. Consequently, snails are primarily consumed by tribal communities in Bangladesh, despite the untapped potential for snail production and export to countries with high demand. Socio-culturally in many countries including Bangladesh, snail shells are used for various recreational purposes, such as home decoration and other events. Industrially, snail shells are valuable for producing raw materials, and their enzymes are utilized in genetic engineering for cell wall treatment. Even the byproducts of snail processing, often considered waste, are essential in agriculture, especially in fish farming **(Solomon, 2013)**. Snails play a vital role in aquatic ecosystems, significantly contributing to nutrient cycling, algae control, and the overall health of the ecosystem. Snails can be used as superior ecological indicators due to their small body size, narrow mobility and position in the food chain.

Most species of snails play a presiding role in the freshwaters by providing food for other organisms like fish and enhance water quality by consuming large quantities of detritus and algae **(Stankovic *et al.*, 2014)**. Due to these potentials of snails, the production of aquaculture in Bangladesh can be increased to a certain extent by diversifying from fish culture along with the inclusion of snails and bivalves. Snails are the focus of numerous research projects globally and are considered important aquatic species. However, snail farming and related research are not common in Bangladesh. Despite their high nutritional value and significant potential for generating revenue and employment, these valuable invertebrate species are often overlooked by researchers. Snails hold promises for boosting both the aquaculture industry and the national economy. Therefore, it is crucial to prioritize diverse investigations and studies on these species to better understand their cultivation potential in Bangladesh. This study aimed to assess the natural abundance and diversity of freshwater snails in three different types of ponds, examining how their abundance and diversity change in relations to variations in water quality and weather parameters.

MATERIALS AND METHODS

Study site

The study was carried out in various types of ponds situated in the Field Laboratory Complex of the Faculty of Fisheries, Bangladesh Agricultural University (BAU) campus, Mymensingh. Geographically, this experimental area lies between 24° 43′ 26″ N and 90° 25′ 48″ E under natural conditions. Three distinct types of ponds were selected based on their culture status: aquaculture, non-aquaculture, and derelict ponds. All three ponds were man-made, rectangular in shape, rain-fed, and well-exposed to sunlight. Their embankments were well-constructed and covered with grass. The aquaculture pond was actively used for fish farming and remained free from aquatic vegetation. Aquaculture pond was free from any kind of external intervention as the pond was used for fish culture on regular basis. The water was not used for activities such as cow bathing, laundry, or dishwashing. As the pond was in continuous use for fish culture, it was monitored by the operator throughout the year. The non-aquaculture pond had previously been used for fish farming but was not engaged in aquaculture activities during the study period. The derelict pond was entirely abandoned and not used for aquaculture. It lacked proper maintenance, clear boundaries, and a defined shape.

Sampling of snails

For the determination of the natural population of varied freshwater snails and mussels, quadrat sampling technique was applied **(Haynes *et al.*, 2015)**. Sampling was conducted once a month, totaling six sampling events from July 2023 to December 2023. Quadrat is a frame that is laid down to mark out a specific area of the community to be sampled. Within the quadrat frame, the occurrence of freshwater snails is recorded using an appropriate measure of abundance. A wooden quadrat ($1m^2$) was placed in the water, and all live snails and bivalves within it were carefully handpicked from the surface and bottom mud. These specimens were then counted and collected for precise taxonomic identification in the laboratory **(del Carmen Esqueda-González *et al.*, 2014)**. The samples were collected from three different locations of each pond based on water depth. The first one was taken from a spot near the edge of water, second one was taken at a moderate distance from the edge of the pond and the third one was taken from the middle point of the pond to make the sample representative form the ponds.

Measuring water quality and weather parameters

During the monthly sampling day of freshwater snails, key water quality and weather parameters such as water temperature, water depth, pH, transparency of water, dissolved oxygen (DO), air temperature and rainfall were measured. Meteorological data, including monthly air temperature and total rainfall, were obtained from the local weather station situated in Bangladesh Agricultural University (BAU) campus.

Identification of snails

The mollusc specimens were identified based on the characteristics as suggested in a published catalogue such as number of whorls, coiling of the shell, umbilicus, shape, color of shell, shape of the aperture, presence or absence of operculum, height and diameter of the snails **(Altaf *et al.*, 2016)**. All the snails found during each sampling date were identified up to species level.

Data analysis

The dataset, used in this study, included the information identified snail and bivalve individuals sampled during the six months of study period. After each sampling, all the data were carefully entered into the MS Excel spreadsheet. Recorded data were computed, and mean values were determined by using Microsoft Excel software. From the dataset, the independent and dependent variables for the Multiple Linear Regression (MLR) model were obtained. MLR is a common statistical method used to analyze how multiple independent variables contribute to the variance in a single dependent variable **(Zientek *et al.*, 2008; Nimon *et al.*, 2010)**. MLR analysis was performed for determining the changes in the number of snails with the changes in various environmental and meteorological parameters. In MLR analysis, water temperature (x_1), water depth (x_2), water transparency (x_3), dissolved oxygen (x_4), pH (x_5), air temperature (x_6) and rainfall (x_7) data were considered as independent variables, while the number of snails per quadrat (y) was considered as dependent variable. The data were analyzed separately for aquaculture pond, non-aquaculture pond and derelict pond based on the following equation of MLR.

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \ldots. + \beta_7 x_7 + \varepsilon$$

Here, y is the dependent or predicted variable (the number of snails recorded per quadrat), β_0 is intercept value, x_i are the seven independent variables, β_i is the regression coefficients representing the change in y relative to a one-unit change in x_i and ε is the model's random error (residual) term, i.e. the variation of our estimate of y with respect to the real value.

In MLR analysis, firstly it is necessary to determine whether there is a linear relationship between the dependent and independent variables. Collinearity diagnostics was done to determine the absence of multicollinearity. Multicollinearity determines important changes in the values of the regression coefficients. The presence of multicollinearity can create problems figuring out the specific variable that contributes to the variance in the dependent variable. We used variance inflation factor (VIF) method to test for the assumption of multicollinearity. To determine the independence of the residuals, the result of Durbin-Watson statistical test was conducted, confirming that the residuals follow a normal distribution. To verify this assumption, a probability (*P*-P) plot was used. The presence of outliers was checked by Cook's distance. The Cook's distance values were always less than 1 indicating the absence of outliers.

The goodness of fit of a multiple regression model was assessed using the coefficient of determination (R^2), with a significance level set at 0.05 (α). The linear determination index R^2 represents the fraction of variance of Y which was explainable by the X regressors included in the model. R^2 showed how well the data points fit a curve or line, while Adjusted-R^2 indicated how well the data points fit a curve or line adjusting the number of data points in a model. Therefore, in MLR with several predictors, it is advisable to consider the Adjusted-R^2 **(Everitt & Skrondal, 2010)**.

RESULTS

1. Production of snails in different types of ponds

Table (1) presents the monthly abundance (number of snails per quadrats) of six mollusc species in aquaculture ponds from July to December. *Pila globosa* shows a peak in August (16 individuals) and a steady decline thereafter. *Bellamya bengalensis* exhibits the highest count in August (56), with a noticeable decrease through December. *Melanoides tuberculata* follows a similar pattern, peaking in August (15) and dwindling to 0 by December. *Macrochlamys sequax* shows low and fluctuating numbers, with a small increase in December (7). *Lymnaea luteola* was absent throughout the period. *Lamellidens marginalis* peaks in August (30) and gradually decreases toward December. The data indicate that most species exhibit higher abundance during the monsoon months (July-August) and decline in the post-monsoon period.

Table 1. Monthly abundance (total number of snails from three quadrats) and diversity of snails in the aquaculture pond

Scientific Name	July	August	September	October	November	December
Pila globose	8	16	9	5	3	3
Bellamya bengalensis	12	56	20	33	17	13
Melanoides tuberculate	9	15	8	5	2	0
Macrochlamys sequax	6	1	4	3	4	7
Lymnaea luteola	0	0	0	0	0	0
Lamellidens marginalis	5	30	10	10	5	3

Monthly variations in the abundance of six mollusc species grown in non-aquaculture ponds from July to December are shown in Table (2). *Pila globosa* peaks in August (28 individuals) and gradually declines through December. *Bellamya bengalensis* has its highest count in September (53), followed by a gradual decrease. *Melanoides tuberculata* remains relatively stable in July and September but drops sharply in October before rising slightly in December. *Macrochlamys sequax* fluctuates, with a notable spike in October (30). *Lymnaea luteola* shows low numbers overall, peaking modestly in September (10). *Lamellidens marginalis* is most abundant in August (49), then declines steadily toward December. In overall, most of the species experience their highest abundance between August and October, followed by a decline in the following months.

Table 2. Monthly abundance (total number of snails from three quadrats) and diversity of snails in the non-aquaculture pond

Scientific name	July	August	September	October	November	December
Pila globosa	20	28	11	11	7	4
Bellamya bengalensis	27	37	53	27	19	15
Melanoides tuberculata	14	20	14	5	4	7
Macrochlamys sequax	21	2	13	30	20	17
Lymnaea luteola	3	4	10	3	6	4
Lamellidens marginalis	29	49	45	30	17	11

In terms of derelict pond, the abundance of *Pila globosa* reached its peak in August (44 individuals) and gradually declined toward December (Table 3). *Bellamya bengalensis* shows a sharp increase in August (93) and remains relatively high through September and October before decreasing. *Melanoides tuberculata* also peaks in August (35) but declines significantly afterward. *Macrochlamys sequax* exhibited a notable rise starting in September, peaking in October (33), and maintaining steady numbers in November and December. *Lymnaea luteola* was absent in July, with a small peak in September (10). *Lamellidens marginalis* showed the highest abundance in August (79), followed by a gradual decline through December. On the whole, August appeared to be the most favorable month for mollusc abundance, with most species showing their highest counts during this period.

Table 3. Monthly abundance (total number of snails from three quadrats) and diversity of snails in the derelict pond

Scientific Name	July	August	September	October	November	December
Pila globosa	17	44	20	16	10	7
Bellamya bengalensis	32	93	73	60	36	28
Melanoides tuberculata	7	35	22	10	6	7
Macrochlamys sequax	5	3	17	33	24	24
Lymnaea luteola	0	4	10	3	6	4
Lamellidens marginalis	11	79	55	40	22	14

The results above reveal clear seasonal patterns in the abundance of six mollusc species across aquaculture, non-aquaculture, and derelict ponds from July to December. In all pond types, August emerges as the peak month for most species, particularly *Pila globosa*, *Bellamya bengalensis*, and *Lamellidens marginalis*. Post-monsoon months witness a general decline in mollusc numbers, though some species like *Macrochlamys sequax* show fluctuations later in the year. The findings underscore the influence of monsoon-driven environmental factors on mollusc populations, with August standing out as the most favorable month for their proliferation across different pond types.

2. Water quality parameters in different ponds

The water quality parameters of three different ponds were assessed from July to December 2023. Key parameters, including water depth, temperature, transparency, dissolved oxygen, and pH, were measured monthly throughout the study period. As previously mentioned, two key meteorological parameters air temperature and rainfall, were collected from the local weather station situated in BAU campus (Table 4).

Table 4. Monthly variation of water quality and weather parameters

Parameters	July	August	September	October	November	December
Water temperature	28.67 ± 0.40	28.37 ± 0.09	29.17 ± 0.13	26.67 ± .12	24.53 ± .29	20.63 ± .249
Water depth	94 ± 6.48	106 ± 7.87	102.33 ± 11.6	117 ± 14.9	96 ± 13.49	82.33 ± 9.46
Water Transparency	34.46 ± 6.03	31.34 ± 5.53	33.3 ± 6.02	33.87 ± 7.3	33.9 ± 10.2	35.43 ± 13.92
Water pH	7.72 ± 0.12	7.64 ± 0.07	7.57 ± .11	7.73 ± .040	7.51 ± .154	7.55 ± 0.14
Water DO	7.10 ± .83	7.78 ± 1.01	7.467 ± 1.09	7.32 ± 1.17	6.81 ± .851	6.61 ± 0.77
Total Rainfall	346.4	463.2	219.6	477.6	3.4	26.5
Air temperature	30.5 ± 3.1	29.9 ± 2.8	30.2 ± 4.1	27.8 ± 3.75	25.1 ± 5.55	21.9 ± 4.5

3. Relationship between snail abundance, and water quality and weather parameters

Table 5. MLR Model summary for aquaculture pond

Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Sum of Squares	df	Mean square	F	p-value	Durbin-watson
Regression	.967	.934	.888	5.647	4535.568	7	647.938	20.316	.000	2.742
Residual					318.932	10	31.893			
Total					4854.500	17				

a. Predictors: (Constant), Rainfall, pH, Water Depth, Water Temperature, DO, Transparency, Air Temperature. b. Dependent Variable: No. of snails/quadrat

Table (5) reveals a significant analysis of variance, indicating a linear relationship between the dependent and independent variables (*P*-value < 0.05). In most cases, R^2 value is between 0 and 1 ($0 \geq R^2 \geq 1$). The R^2 and adjusted R^2 indicate how well the regressors are suited for predicting the values of the dependent variable in the sample data. If R^2 (or Adjusted R^2) tends to 1, the regressors produce good predictions of the dependent variable, if R^2 (or Adjusted R^2) tends to 0 the opposite is true. Here, from the model summary of aquaculture pond, the adjusted R^2 value is 0.888 showing that the model explains 88.8% of the variance in the % of snail abundance with a significant level (α) of 0.05. The Cook's distance for each observation was below 1, indicating the absence of influential outliers affecting the coefficient estimates. The highest computed Cook's distance value was 0.734, well below the threshold of 1. We primarily focus on the Sig. column of *P*-value (Table 5), which provides the *P*-value for the R^2 statistic. If the *P*-value exceeds 0.05, the model is not statistically significant, requiring the analysis to be discontinued. In this case, the *P*-value is below 0.05, indicating that the overall model fit is statistically significant. The Durbin-Watson test statistic ranges from 0 to 4, with values between 1.5 and 2.5 indicating the absence of autocorrelation **(Chapman *et al.*, 2004)**. Durbin-Watson value was found to be just above the acceptable range.

Table 6. Standardized and unstandardized coefficients with *P*-values of the MLR analysis for aquaculture pond

Variable	Unstandardized Coefficients		Standardized Coefficients	t	p-value	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	84.325	277.227		.304	.767		
Water Temperature	3.785	9.192	.699	.412	.689	.002	438.150
Water depth	-1.125	.126	-.944	-8.930	.000	.588	1.700
Transparency	-7.318	5.535	-1.053	-1.322	.216	.010	96.488
pH	14.345	41.499	.091	.346	.736	.095	10.496
DO	-3.400	6.825	-.128	-.498	.629	.099	10.118
Air temperature	1.267	12.538	.242	.101	.922	.001	875.880
Rainfall	.086	.017	.995	4.957	.001	.163	6.132

The estimated model parameters (Table 6) in the B column provide the β coefficients for the prediction equation. Table (6) also shows the results of the t-test, used to study the significance of the regression coefficients (βi). The *P*-value was less than 0.05 (considered significant) for the water depth and rainfall. Among these variables that significantly influence snail abundance, rainfall exhibits the highest coefficient. The values of VIF, and tolerance obtained for each independent variable are also demonstrated. Since the VIF values were sometimes greater than 10 and the tolerance values were occasionally below 0.2, multicollinearity was detected in some of the variables.

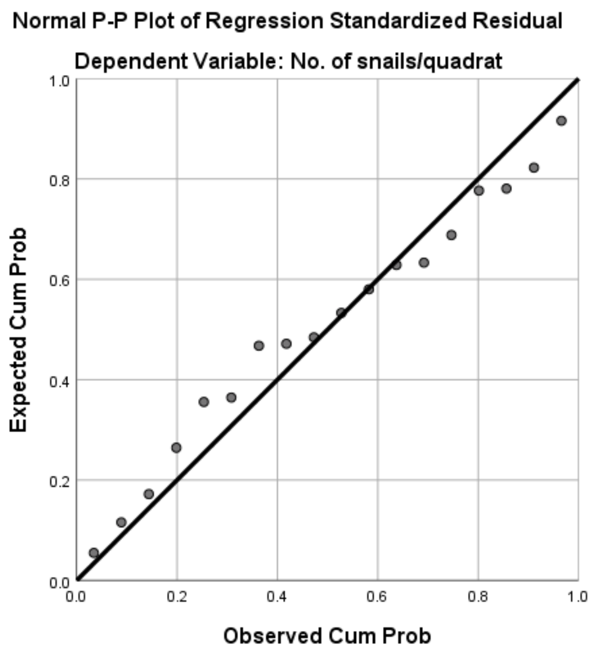

Fig. 1. Normal *P*-P plot of standardized residual for aquaculture pond

Fig. (1) exhibits the *P*-P (Probability-Plot) plot, a graph ‘observed value’ against ‘expected normal value’. In MLR, a *P*-P plot is used to assess whether the residuals (the differences between observed and predicted values) follow a normal distribution. This is important because one of the key assumptions of linear regression is that the residuals are normally distributed. X-axis defines the cumulative probability of the actual residuals from the regression model and Y-axis defines the cumulative probability expected if the residuals followed a perfect normal distribution. This is observed in Fig. (1), where the data points are close to the line indicating the normal distribution of the residuals.

Table 7. MLR model summary for non-aquaculture pond

Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Sum of Squares	df	Mean square	F	p-value	Durbin-watson
Regression	.861	.741	.560	20.612	12155.924	7	1736.561	4.087	.022	2.676
Residual					4248.520	10	424.852			
Total				16404.444	16404.444	17				

a. Predictors: (Constant), Rainfall, pH, Water Depth, Water Temperature, DO, Transparency, Air Temperature

b. Dependent Variable: No. of snails/quadrat

In case of non-aquaculture pond, the adjusted R^2 value is 0.560, indicating that the model explains 56% of the variance in the percentage of snail abundance. Since the *P*-value is 0.022, which is below the 0.05 threshold, we can conclude that the overall fit of the model is statistically significant (Table 7).

Table 8. Standardized and unstandardized coefficients with *P*-values of the MLR analysis for non-aquaculture pond

Variable	Unstandardized Coefficients		Standardized Coefficients	t	p-value	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	-2264.990	2140.984		-1.058	.315		
Water Temperature	101.234	26.311	9.819	3848	.003	.004	251.462
Water depth	-2.407	.514	-1.186	-4.679	.001	.403	2.480
Transparency	-1.328	7.197	-.053	-.185	.857	.310	3.222
pH	293.211	272.885	1.525	1.074	.308	.013	77.769
DO	68.737	71.237	.808	.965	.357	.037	27.043
Air temperature	-100.441	27.719	-10.454	-3.624	.005	.003	321.361
Rainfall	-.084	.267	-.530	-.315	.759	.009	109.611

The air temperature, water depth, and water temperature all had *P*-values less than 0.05. Water temperature has the largest coefficient among these independent variables that have a substantial impact on snail abundance. Multicollinearity was found in some of the variables because the tolerance values were occasionally less than 0.2 and the VIF values were occasionally larger than 10 (Table 8).

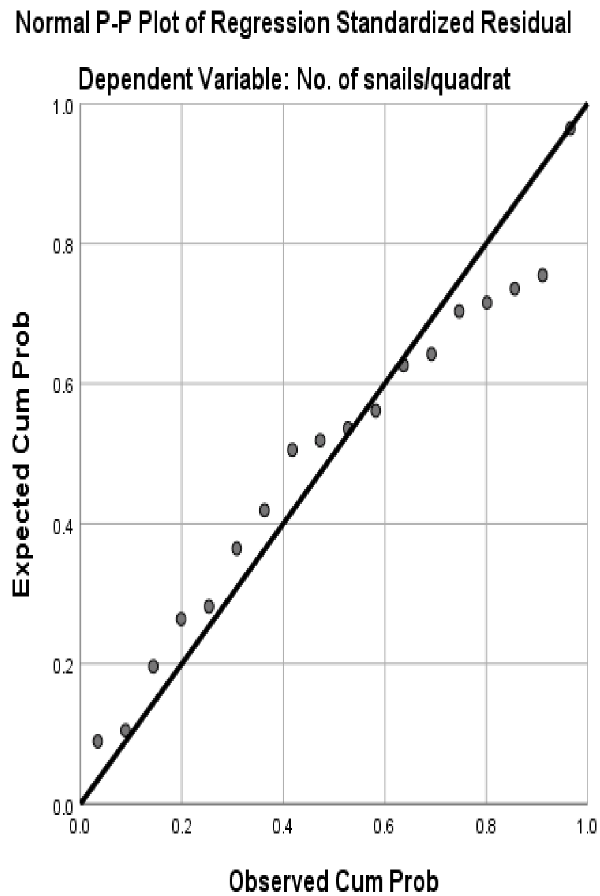

Fig. 2. Normal *P*-P Plot of standardized residual for non-aquaculture ponds

The points in this plot are fairly close to the diagonal line, indicating that the residuals are approximately normally distributed. There are slight deviations in the upper range, suggesting minor departures from normality, possibly due to heavy tails or a few outliers. However, these deviations appear small, meaning the normality assumption is reasonably satisfied for regression analysis (Fig. 2).

Table 9. MLR model summary for derelict pond

Model	R	R^2	Adjusted R Square	Std. Error of the Estimate	Sum of Squares	df	Mean square	F	*P*-value	Durbin-watson
Regression	.887	.788	.639	14.831	8156.954	7	1165.279	5.298	.009	2.941
Residual					2199.490	10	219.949			
Total				16404.444	10356.444	17				

a. Predictors: (Constant), Rainfall, pH, Water Depth, Water Temperature, DO, Transparency, Air Temperature

b. Dependent Variable: No. of snails/quadrat

According to the model summary for the derelict pond, the adjusted R² value is 0.639, indicating that the model explains 63.9% of the variance in snail abundance. Since the significance level (α) is set at 0.05 and the observed *P*-value is below this threshold, the model's overall fit can be considered statistically significant (Table 9).

Table 10. Standardized and unstandardized coefficients with *P*-values of the MLR analysis for derelict pond

Variable	Unstandardized Coefficients		Standardized Coefficients	t	p-value	Collinearity Statistics	
	B	Std. Error	Beta			Tolerance	VIF
(Constant)	-671.458	1296.755		-.518	.616		
Water Temperature	29.387	12.378	3.690	2.374	.039	.009	113.763
Water depth	-2.531	.488	-1.310	-5.182	.000	.332	3.009
Transparency	-2.335	2.663	-.523	-.877	.401	.060	16.747
pH	126.320	175.206	.320	.721	.487	.108	9.267
DO	19.016	24.205	.253	.786	.450	.205	4.887
Air temperature	-30.838	12.846	-4.039	-2.401	.037	.008	133.323
Rainfall	.099	.050	.787	1.984	.075	.135	7.403

In this case, the *P*-values for water temperature, air temperature, and water depth were all below 0.05, indicating statistical significance. Among these parameters, water temperature had the highest coefficient. Additionally, some variables exhibited signs of multicollinearity (Table 10).

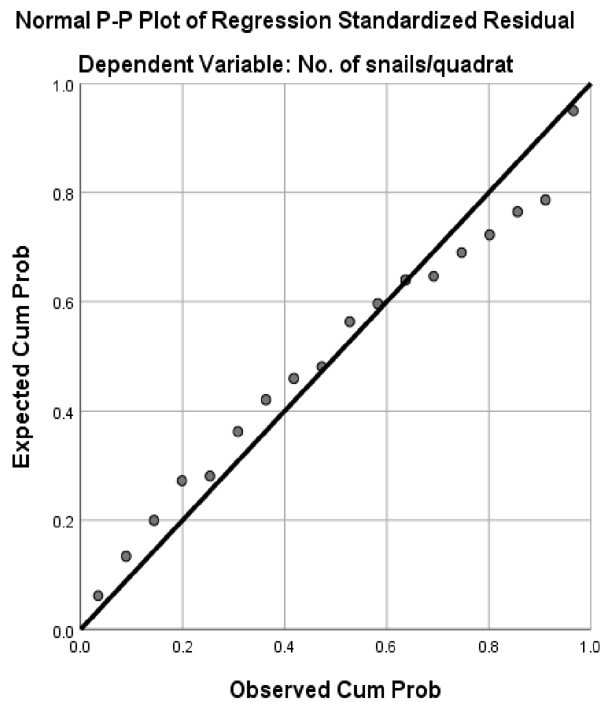

Fig. 3. Normal *P*-P Plot of standardized residual for derelict pond

In the P-P plot, the data points align approximately along a straight line, suggesting that the residuals are normally distributed. This alignment indicates that the normality assumption is likely satisfied, supporting the validity of regression model (Fig. 3). Although a few outliers are present, they do not significantly affect the accuracy of the coefficient estimates.

DISCUSSION

The study investigated how changes in snail production are influenced by various water quality and weather parameters in different types of ponds. Multiple Linear Regression (MLR) analysis was employed to explore the relationship between snail abundance, and water quality and weather parameters, based on the observations for a period of six months.

Five species of freshwater snails and one species of mussel under two taxonomic classes, and six families were found from the selected ponds, viz. *Pila globosa*, *Bellamya bengalensis*, *Melanoides tuberculata*, *Macrochlamys sequax*, *Lymnaea luteola*, *Lamellidens marginalis*. The number of specimens identified in aquaculture, non-aquaculture, and derelict ponds varied considerably. Derelict pond had a higher concentration of snails than the other two types of ponds, with Guli Shamuk (*Bellamya bengalensis*) being particularly prevalent. Apple Shamuk (*Pila globosa*) and Gol Shamuk (*Macrochlamys sequax*) were substantially more common in non-aquaculture ponds. A lower number of snails was observed in the aquaculture pond, likely due to the presence of fish that prey on snails, thereby controlling their population. Additionally, routine pond cleaning and maintenance, such as removing debris and vegetation that could serve as snail habitats, contribute to reducing their numbers. The use of chemical treatments for algae control can inadvertently affect snail populations **(Liu *et al.*, 2012)**.

Species and their numbers varied throughout the study period (July to December). The majority species of snails were more abundant in August and September. Although snails were observed in every month of the study period, there was a considerable decrease in their abundance from July to December. Their maximum abundance was found in August and they started to decline in the following months. December was the month that showed the lowest abundance of snails. During sampling, a large quantity of dead snails and mussels were found particularly in November and December. This is possibly due to the impact of winter conditions on the reproduction and growth rates of snails. Cold temperatures may slow down the reproductive cycles of snails, leading to fewer young snails being present in the environment during December **(Kop, 2018)**.

For aquaculture pond, the results of MLR analysis demonstrate that water depth, water transparency and rainfall are the variables that most influence the abundance of snails. Rainfall exhibits the highest coefficient among all the variables that significantly influenced snail abundance in aquaculture pond. On the other hand, the statistics of t-test for non-aquaculture pond show that the variables that most affect the snail population are air temperature, pH, water temperature, and water depth, with water temperature exhibiting the highest coefficient. The findings from the derelict pond identified water temperature, water depth, air temperature, and rainfall as the most critical factors influencing total abundance. Among these, the water temperature exhibited the largest coefficient, highlighting its significant impact on snail abundance.

Previous studies have shown that environmental factors, including water physico-chemical quality and human and animal activities, affect snail abundance **(Posa & Sodhi, 2006; Kibria & Haque, 2018)**. Higher temperatures enhance the metabolic rate, fecundity, and feeding frequency of snails shortening developmental periods while increasing the number of generations per year and overall population size **(Kristensen *et al.*, 2001)**. Warmer temperatures can lead to increased primary productivity in aquatic environments, which can enhance the availability of food organisms for molluscs. This can lead to increased abundance of mollusc species that rely on phytoplankton or algae **(Peinado *et al.*, 2010)**. A negative correlation between temperature and molluscs is also found, as elevated temperatures can cause thermal stress, reduce survival rates, and even lead to mortality, especially when temperatures exceed the tolerance thresholds of the species **(Bultel *et al.*, 2012)**.

Among the physico-chemical properties of water, dissolved oxygen plays a crucial role in determining snail species abundance. Low oxygen saturation indicates poor water quality. Oxygen saturation showed a positive correlation with the abundance of *B. pfeiferi* but a negative correlation with *B. globosus* **(de Troyer *et al.*, 2016)**. We also found a positive relationship between dissolved oxygen levels and snail abundance. **Miller and Allen (2017)** reported that some molluscs can survive in extremely low oxygen conditions and observed an inverse relationship between oxygen levels and their abundance.

Additionally, water depth has been shown to affect the distribution patterns of snail species, with their abundance decreasing as water depth increases **(Heller & Gonzalez, 2003)**. The mean pH value in all the water bodies in the present study was within favorable limits for aquatic snail production **(Boelee & Laamrani, 2004)**. In aquatic environments, the wet season causes water levels in ponds, lakes, and rivers to rise. This increase in water volume expands the available habitat for aquatic snails, potentially leading to higher abundance as more areas become accessible for colonization **(Baker & Palmer, 2015)**.

Although the study is innovative in terms of sample size and the associated factors examined, it has some limitations. The current estimate of snail abundance and diversity may be a minimum, as very small individuals were difficult to catch, and some may have remained under the mud during the quadrat sampling. In the multiple linear regression (MLR) analysis, multicollinearity was occasionally present due to the large dataset and high variation. Multicollinearity among key predictors is sometimes unavoidable. To mitigate this, collecting additional data and exploring alternative predictors or approaches, such as ridge regression, could help reduce collinearity.

Freshwater snails reproduce rapidly in ponds irrespective of pond types, with their production closely linked to environmental and climatic conditions **(Alam *et al.*, 2024)**. These snails play a vital role in environmental remediation and mitigating climate change impacts, contributing to nutrient cycling, algae control, and ecosystem health. They also have various industrial applications, serving as raw materials for enzyme extraction and as key ingredients in fish and animal feed production. Despite their significant potential, snail farming remains absent in Bangladesh. Globally, Integrated Multi-Trophic Aquaculture (IMTA) is gaining importance as a sustainable approach to balance environmental health, economic viability, and social benefits. Snails or any potential molluscs are essential in IMTA systems as organic extractive species, making their cultivation a sustainable and necessary practice for advancing aquaculture in the country.

In Bangladesh, substantial research has been conducted on the finfish aquaculture, encompassing both small-scale and commercial practices, as well as the impacts of climate change **(Haque, 2007; Little *et al.*, 2007; Haque *et al.*, 2014; Bremer *et al.*, 2016; Alam *et al.*, 2019; Haque *et al.*, 2021b; Hasan *et al.*, 2021; Hoque *et al.*, 2021; Siddique *et al.*, 2022a; Siddique *et al.*, 2022b)**. However, research on molluscs, including their ecology, biology, distribution, and aquaculture potential, has been limited, particularly in the context of Bangladesh. To address this gap, it is crucial to enhance research efforts, ranging from fundamental laboratory studies to applied research on molluscan species, with an emphasis on integrating them into aquaculture practices like IMTA.

CONCLUSION

In the face of increasing anthropogenic activities and climate change impacts on aquatic ecosystems, there is a pressing need to assess and monitor the abundance and diversity of key organisms like freshwater pond snails. Recognized globally as important aquatic species, snails have been the focus of extensive research. In Bangladesh, shifting beyond traditional finfish culture to include valuable mollusc species like snails and bivalves can significantly enhance aquaculture productivity. This study identified potential snail species during a six-month sampling period and employed statistical analysis using the MLR model to examine the influence of variables such as water temperature, depth, air temperature, and rainfall on snail abundance and diversity. The results are consistent with growing literature, emphasizing the influence of these factors on snail abundance in aquatic environments. The study also highlights the potential for integrating snails into modern aquaculture techniques like IMTA, where snails could coexist as organic waste extractive with fish, plants, and other organisms, benefiting from each other's waste and by-products. However, the study was conducted over a relatively short period. A year-round study would provide more comprehensive insights by covering the entire production cycle of snails. Relating to such studies, further research could also integrate with the faming of snalis and other potential molluscs in IMTA systems.

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