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# DOES THE EXPLOITATION OF THE SNAIL *FILOPALUDINA BENGALENSIS* FOLLOW THE NORMS OF SUSTAINABILITY? AN ASSESSMENT BASED ON ECOLOGICAL MODELS

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**Abstract.** Freshwater snails draw attention for being a cheap resource of proteins, fatty acids, vitamins, and minerals in eastern and north-eastern India, as well as in south-east Asia. They are harvested from water bodies to serve the local economically impoverished people or sold as a commodity in local fish markets. Owing to the growing demand, the unregulated harvest of the snails may push their population to decline drastically at the local level. The snails sold in markets are segregated based on size to attract the best price, which may bias the catch towards more suitable sizes. The catches from markets and water bodies were analyzed simultaneously for the maximum sustainable yield (*MSY*) of snails, providing future guidelines for sustainable harvesting. The catch per unit effort (*CPUE*) has been used as a novel proposed equation to calculate the *MSY*. The equation used in this article is $MSY = CPUE_{Market} / CPUE_{Field}$. The size-wise variability (measured through the diversity *H′*) represented through the abundance of various shell length classes affected the total catch of the snails. The demand-wise segregation at markets biases the catch, as sizes differ between markets and water bodies. The present analysis provides the basis of guidelines for sustainable harvesting, though it requires further research using a novel concept of sustainable yield or *CPUE* and deducing newer methods for the calculation of sustainable harvesting.

## INTRODUCTION

Freshwater snails (Mollusca: Gastropoda) are considered a cheap source of protein and minerals in many parts of India (Cobbinah et al. 2008; Ghosh et al. 2016; Shathi et al. 2022; Jadhav et al. 2023; Lourembam and Singh 2023; Subba Rao 1989; Tripathy and Mukhopadhyay 2015) and other south and southeast Asian countries (Dung et al. 2010; Madsen and Hung 2014; Chantima et al. 2018; Sutcharit et al. 2020; Debnath et al. 2016; Bar 2020; Luo et al. 2022). Freshwater snails are harvested from the rivers, canals, ponds and other wetlands and reach the consumers through the local fish markets. However, information on the harvest pattern and the preferences among the consumers is little known in India and other countries. Recent documentation on freshwater snails as an edible resource indicated a wide range of exploitation of the species in the eastern and north-eastern regions of India (Jadhav et al. 2023). The aquaculture concerning snails for economic harvest is getting more attention (Coelho et al. 2012). The people collect the snails and segregate them by size according to market demand, and the extra snails are discarded or returned to the water bodies (Meyo et al. 2021). Such harvest, if continued for a long time, without regulation or following the norms of sustainability, may pose a risk of extinction, even at the local scale. This calls for a monitoring system that would highlight the harvest pattern of the snails and their availability along with the consumer's choice and pricing.

In the Indian context, as well as in south Asia, freshwater snails are abundant, but considering the risks of overexploitation, the harvested species may decline extensively. This may be a reason to monitor the harvest pattern of the freshwater snails, not only to assess the demand and utility but also to frame an appropriate strategy to secure the supply for the future (Massari and Pastore 2014; Meyo et al. 2021). Aquatic animal food resources are vastly susceptible to non-specific exploitation, which reduces the sustainable utility and thereby poses a concern for food security (Massari and Pastore 2014; Meyo et al. 2021; Khalua et al. 2014; Bar 2020; Mondal et al. 2023). Alike most of the resources utilized through capture fisheries, an account of the present harvest pattern in parity with the availability is essential for sustainability.

Thus, the present study was aimed at the assessment of the exploitation pattern of the freshwater snail *Filopaludina bengalensis* as a food resource in Kolkata, India and adjacent areas. Empirical evidence recorded the information on their abundance and availability in the freshwater bodies, though the level of exploitation and the harvest methods are little known to highlight their inclusion in sustainable aquaculture.

For market catch, it would not be wrong to state that the sellers intentionally segregate the medium-sized snails to sell (Jatau and Shidiki 2006), as it would attract more profit and destroy the rest. But from the field, the unbiased catch also yielded the medium-sized snails at its peak. This observation can potentially attract interest in analyzing the contribution and effect on the snail population for their survival. The harvested snails are sold for economic purposes (Massari and Pastore 2014; Meyo et al. 2021; Jatau and Shidiki 2006). A conventional line of earning had risen, focusing on the snails and mussels in the markets. The price of the snails does not depend on the size. The local sellers sell it as an aggregated mass of different-sized snails. Rather the price depends on the area of harvesting and area of marketizing, for its effort imparted on harvesting and transport cost to the market (Cobbinah et al. 2008; Kareem et al. 2021; Jadhav et al. 2023). Again, it can be stated that as the price does not depend on size, the medium size gains the greatest financial profit.

The snails are harvested throughout the area without any harvesting bar, as they can create a large population within a limited time. Still, there lies a chance of crashing of the snail population (Massari and Pastore 2014; Meyo et al. 2021). To prevent that, a sustainable harvest approach has to be considered. Sustainable catch or yield implies that the harvest of one season imitates the same yield for the next season. The harvest is done in such manner that it does not crash the population to extinction, the harvest is allowed to a certain margin, so that the sexually mature adults get an opportunity at least once in a lifecycle to reproduce, and the population is maintained with newly hatched young. However, with the sustainability of the population, the economic profit of sellers has also to be taken into account, i.e., to gain maximum economic profit while the population is maintained too. This limit of harvesting is known as the maximum sustainable yield (*MSY*), where the sellers enjoy the highest profit possible without affecting the snail population. The *MSY* is a theoretical concept of the number or mass of catch exploited from the population, so that the population is maintained to provide the same amount of harvest for the next season yield. For assessing the economic profit, not only the harvest is considered, rather, the effort imparted has also to be included. The net profit from harvesting can only be evaluated if the cost of effort is included. The catch per unit effort (*CPUE*) is another parameter for analyzing the yield and profit. In this article, the *MSY* is hypothesized to be calculated from the *CPUE*, other than the traditional method of calculation. Here, the *CPUE* was also extended to be a function of size class diversity to analyze the difference in size-class-wise *CPUE* and *MSY* values. A new approach has been taken to assess sustainable snail harvest affected by size class diversity, the change in *CPUE* and *MSY* has been analyzed with modified equations.

Several studies have also shown that an individual as well as a dead shell are crucial in the maintenance of the ecosystem health of the concerned water bodies (Hoverman et al. 2011). Therefore, evaluation of these species as a natural capital is essential to sustain the ecosystem services derived from these snails. Accordingly, in the present study, the availability of the snails in the ponds and allied freshwater bodies and the local markets were made to assess the concurrence of the harvest pattern. The results are expected to provide the value and preference of freshwater snails as a food commodity in the concerned geographical area. Information obtained from the present study will enable framing appropriate strategies for sustainable harvest and a possibility of culture of these species for food security.

## MATERIALS AND METHODS

### *Field collection of the snails*

The freshwater snails *Filopaludina bengalensis* were collected from a varied type of wetlands in and around Kolkata (22.5744° N, 88.3629° E), India, using different collection techniques. Using a net fitted with a long handle, the snails were collected from the upper water column, and later the net was dredged along the sediment as well as through the vegetation. In addition, an effort was given to find the snails attached to the physical structures like the bamboo stumps and the various sticks immersed in the water bodies. All these sampling techniques were employed for each and every studied water body, and the snails collected in cumulative collections were considered to be the sample for a particular water body. In a particular water body, at least three such collections were considered between July and October of 2012 and 2016, coinciding with the monsoon period. During the sampling, various snails like *Racesina luteola, Indoplanorbis exustus, Gyraulus convexiusculus, Pila globosa, Melanoides tuberculata,* and *Thiara lineata* were obtained in few to considerable numbers which were not considered for study. After placing *F. bengalensis* in the sample bags (plastic bag of 45 × 60 cm size), the rest of the snails were discarded and placed back in the water bodies. *F. bengalensis* of varied sizes were placed in the plastic bags with around 200 ml of water and brought to a laboratory for segregation based on shell length (in mm). A record of the abundance of snails on the basis of respective size classes could be deduced through observations on shell length. The body weight of individual snails was also noted for further analysis. The shell length (in mm) of an individual snail was measured using a vernier calliper, and the body weight was taken in a pan balance (Afcoset, India) to the nearest 0.1 mg and recorded.

### *Market collection of the snails*

Following an initial survey of the fish markets in Kolkata, India, and adjoining areas including the districts of Howrah, Burdwan, Hooghly, North and South 24 Parganas, the freshwater snails *F. bengalensis* were collected on a consistent basis for a period between 2014 and 2016. The collection of *F. bengalensis* was carried out each month for two years, from 2014 to 2016, to assess the differences of various size classes of the snails sold and to validate the condition factor. Generally, the sellers stock the saleable snails in jute or plastic bags weighing no less than 100 kg. A random selection of the snails was made from the sellers. For a set quantity of 200 g, the samples were collected randomly from different vendors in different time, such that each sample qualifies for being a true replicate (Hurlbert 1984) for analysis. The collected samples were brought in the laboratory and recorded on the basis of the shell length size classes, price and the abundance in each size class. The snails were differentiated on the basis of size class, abundance, and price in the fish markets.

The snails harvested were of different sizes. To standardize the analysis, the harvested snails were differentiated into seven size classes, from 10.1 to 45 mm, ranging for 10 mm for each size class, based on their shell length. Different size classes were analyzed separately considering size class diversity for each catch both from the market and the field. The median size class was observed to have the greatest abundance (Table 1).

### *Data analysis*

### *General*

Data on shell length and body weight of the individual snails collected from the field as well as the markets were correlated with the pricing pattern. Initial data on the abundance of snails in the field and markets were subjected to a logistic regression based on the binomial generalized linear model (GLM) with logit link. The snails sold in the market were characterized based on the shell length and the body weight of the individuals in the sample for each month. Variability in the biomass obtained per unit price was portrayed through the best fit regression equation, using the biomass and shell length as explanatory variables. The unit selling price of the snails and the mussel (Indian Rupees, INR) was replaced as a standardized price using the formula stated below:

Standardized price = (price in INR *100)/ maximum price

(INR – Indian rupees)

Assuming a generalized linear model (GLM), the data on the abundance of mussels were subjected to logistic regression (binomial GLM using a logit link) with size class and sites (market and field data) as predictors. In this regression, it is assumed that the relative abundance of snails follows a binomial (n, p) distribution with n replicates for each combination of explanatory variables (size class and sites). The linear combination of the explanatory variables is presented through the probability parameter p. A logit link was used with the parameters being estimated through the maximum likelihood method using statistical software (XLSTAT, Addinsoft 2010). The significance of the estimated parameters of the GLM including the site and the size classes was deduced through Wald $\chi^2$ value. The results were used to justify the heterogeneity in the representation in the size classes and availability in the market and the field. The proportional presentation of the size classes in the field and the market were tested using a one-tailed *t*-test to find the deviation from unity, to judge the relative abundance of the exploited and available snails. A

Table 1. Monthly variations in the size class abundance of *F. bengalensis* in the fish markets in and around Kolkata and suburbs, India, surveyed between 2014 and 2016.

| Month | Shell height | Shell width | Body weight | Market price |
|---|---|---|---|---|
| JAN | 29.81 ± 1.07 | 22.22 ± 0.80 | 4.44 ± 0.36 | 54.81 ± 4.24 |
| FEB | 31.55 ± 1.27 | 23.35 ± 0.80 | 4.67 ± 0.55 | 46.84 ± 1.09 |
| MAR | 31.04 ± 0.78 | 23.02 ± 0.49 | 4.82 ± 0.32 | 45.86 ± 0.76 |
| APR | 28.33 ± 0.92 | 20.99 ± 0.63 | 3.34 ± 0.25 | 20 ± 0 |
| MAY | 30.07 ± 0.84 | 21.64 ± 0.57 | 3.62 ± 0.22 | 20 ± 0 |
| JUN | 19.40 ± 1.90 | 13.45 ± 1.38 | 1.76 ± 0.26 | 30 ± 0 |
| JUL | 20.8 ± 3.28 | 13.86 ± 2.48 | 2.36 ± 0.28 | 30 ± 0 |
| AUG | 31 ± 1.19 | 21.09 ± 0.83 | 4.17 ± 0.43 | 46.87 ± 1.01 |
| SEP | 30.26 ± 1.64 | 20.09 ± 1.03 | 3.95 ± 0.43 | 48.57 ± 0.97 |
| OCT | 31.38 ± 0.60 | 21.38 ± 0.43 | 3.95 ± 0.23 | 25 ± 2.65 |
| NOV | 30.48 ± 0.55 | 22.66 ± 0.41 | 4.56 ± 0.19 | 27.38 ± 0.95 |
| DEC | 28.82 ± 0.85 | 21.21 ± 0.66 | 3.92 ± 0.28 | 54.8 ± 4.39 |

Friedman's paired comparison was applied to the data on proportional representation in each size class of the snails in the fish markets and the wetlands.

### The model assessing sustainability

The catch per unit effort (*CPUE*) is a general term used to define the aquatic product harvested or available at a certain time point. The *CPUE* was introduced to judge the amount of the harvest made and a comparison to assess the sustainability of the yield. In several occasions, the *CPUE* was used to judge the harvest of the fish from both freshwater and the sea as well as various edible aquatic organisms including molluscs.

To comply with the sustainability principles, the snails harvested and snails sold in the market must remain in balance, i.e., the number of snails harvested in the present instance should remain similar to those sold in the market. Further, this balance should be maintained at different time points of harvest, such that the number of snails caught in the next year must resemble the catch of the previous year, thereby sustaining the resource availability. Accordingly, a maximum sustainable yield (*MSY*) is the maximum profit from a snail catching/harvest (Vincenzi et al. 2006; Robinson et al. 2007; Van Wynsberge et al. 2013; Mafambissa et al. 2022; Soniat et al. 2022), so that it remains the same for the next year. Thus, on the basis of this theory, the monitoring of the field and the natural habitat data on the snail species should comply in terms of the proportional representation of the size classes to qualify as a sustainable harvest. We used a generalized estimation of the snail harvest by calculating the *CPUE* (catch per unit effort) $[CPUE = \frac{Yield(C)}{Effort(E)}]$. Here, we have assumed the collections made from the different ponds in each sampling to be the *CPUE*, i.e. collection of the snails carried out during a particular time period. It was hypothesized that if the ratio of the catch of the market and the field is equal to 1, the resource is at MSY and can be harvested the same way in the next catch.

The snails harvested were divided into seven size classes, and for each class the diversity index ($H'$) was calculated. Here, the types of size classes and the relative abundance of each class were used to calculate the $H'$. A new approach to define *CPUE* using $H'$ was initiated and the modified *CPUE* was expressed as $CPUE''$.

$$CPUE'' = CPUE \times H'$$

$$CPUE'' = \frac{C}{E} \times H' \qquad (1)$$

where $C$ is the catch, and $E$ is the effort implied.

The catch from the market and the field are compared to derive the maximum sustainable yield (*MSY*), which is predicted to be 1, so that catch is at *MSY*. The *MSY* is 0.61 for classical *CPUE* and 0.66 for modified *CPUE*, which state that the snails in the field are in sustainable state and the catch can be increased to get more profit from catching snails.

The snails caught could be classified into seven different size classes, from which the diversity of each catch could be deduced. As a proposition we deduced that the diversity (of size classes) in the catch will be related to the CPUE, which can be expressed in equation 1. From equation 1 it can be derived how the modified *CPUE* changes with changing diversity ($H'$):

$$\frac{dCPUE''}{dH'} = 1 - \frac{L_c}{L_{obs}} \qquad (2)$$

where, $L_c$ is mean length of each size class, and $L_{obs}$ is the highest length observed in the largest size class. On integrating equation 2 we get

$$\int dCPUE'' = \left(1 - \frac{L_c}{L_{obs}}\right)\int dH'$$

$$CPUE'' = \left(1 - \frac{L_c}{L_{obs}}\right) H' + c \qquad (3)$$

where $c$ is the integration constant, $c = CPUE''$ at diversity = 0, i.e., $c = CPUE_0$

$$CPUE'' = \left(1 - \frac{L_c}{L_{obs}}\right) H' + CPUE_0 \qquad (4)$$

So, the operational *CPUE* is related to the shell length-based diversity and the shell length. For correlating the *CPUE* with the parameters mentioned in the RHS, the $CPUE_0$ is assumed to be 0, considering that the harvest of *F. bengalensis* was not made of a single size class only (Supplementary file).

$$CPUE'' - CPUE_0 = \left(1 - \frac{L_c}{L_{obs}}\right) H' \qquad (5)$$

To ensure that the catch is heterogeneous, i.e., comprising multiple size classes, we considered diversity as the assorted size classes of the snails. Thus, diversity is reflecting the heterogeneity of the size classes in the representative samples. A state of 0 diversity value will mean that the catch of the snails is of the same size class. When the catch is from a single size class, homogeneity is maximum, resulting in zero diversity. Thus, the value of $CPUE_0$ is considered to be zero. In a real catch, various size classes are present, for which there will be some level of heterogeneity. A deviation of *CPUE* from $CPUE''$ (Supplementary file) will indicate the significance of the heterogeneity of the size class. The diversity of each size class directly affects the catch, and some size classes are affected more than the others as analysed, especially for the lower size classes, may be due to their capability of escaping the gear. The larger size classes consequently reach a length that is easily available.

## RESULTS

The freshwater snail *F. bengalensis* was found consistently in the fish markets with variations in the size classes among months (Table 1). The application of the

Table 2. Results of binomial GLM with logit link representing the differences in the abundance of the size classes of *F. bengalensis* (FBE) against the month as observed in the samples obtained from the fish markets of West Bengal, India: (a) the logistic regression equations and (b) the significant test for the parameters of the model (size class, month and month and size class interaction).

(a)

| |
|---|
| $\text{Abundance}_{FBE} = 1 / (1 + \exp (-(-1.96 – 0.206 \times \text{Month} - 0.466 \times \times \text{Size} + 0.07 * \text{Month} * \text{Size})))$ |

(b)

| FBE | | | |
|---|---|---|---|
| Value | -0.407 | -0.176 | 0.518 |
| SE | 0.111 | 0.043 | 0.118 |
| Wald $\chi^2$ | 13.483 | 17.033 | 19.213 |
| Pr > $\chi^2$ | 0.000 | < 0.0001 | < 0.0001 |

logistic regression indicated significant differences in the monthly abundance of different size classes of these snails, indicating variability in the exploitation of size classes over time (Table 2).

The shell length and body relationship in the species complied with the power regression, which appears to be similar to those observed for *F. bengalensis* in Kolkata, India (Khan and Chaudhuri 1984). The samples obtained from the market indicated the price of snails in the fish markets was an increasing function of size (Figures 1–3). As shown through the regression equations, for *F. bengalensis* the standardized price was observed to increase with the increase in the body weight and shell length (Figures 1–3). A power regression was the best fit for the snail *F. bengalensis*

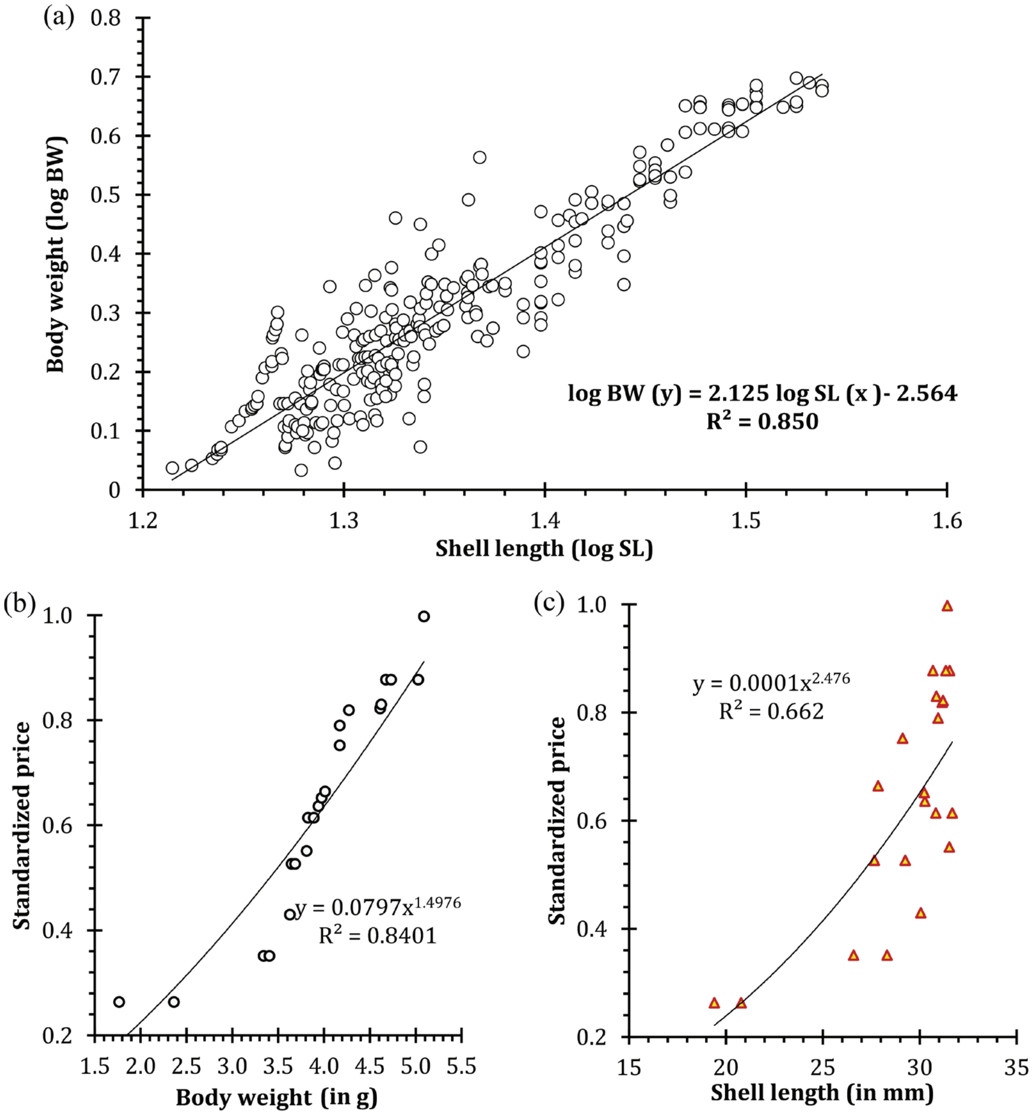

Figure 1. The relationship between shell length and body weight (a) of the viviparid snail *F. bengalensis* collected from the fish markets in and around Kolkata and suburbs, India, during 2014 and 2016 (n = 345 random samples from different fish markets). The log transformed values are shown in the graph. The standardized selling price of the freshwater snail *F. bengalensis* against body weight (b) and shell length (c) as observed in and around Kolkata and suburbs, India. Instead of the currency, the standardized prices are considered in the analysis (n = 60 pairs from different fish markets). The best fit regression equations are shown in the graphs.

(Figure 1). The biomass per unit price of *F. bengalensis* followed a power equation against biomass and the shell length of the individuals (Figure 2). The shell length and the biomass of the snails are related through a power regression. The overall increase in price was observed against biomass (Figure 3a and b), but when sold as a unit, the proportional representations of each size class varied, for which the observed differences remained undermined. Therefore, individuals of a smaller biomass, being present in the same assorted unit, were sold at the same unit price as those of bigger size classes. Thus, the medium size classes of the snails were more profitable for the buyers than the larger size classes. Compared to the cultured fish as well as small indigenous fish species, it was apparent that the pricing of the snails may not be linear to the biomass or shell length.

Using both relative numbers and proportion in the samples, the ratio of availability in the field and in the fish market indicated the differences, if any, in the size classes (Figure 3).

Similarly, for the snail *F. bengalensis,* it was only in a single size class (25.1–30 mm) that the difference in the relative representations in the wetland and in the fish market samples were observed (Table 3). For the rest of the samples, the ratio of relative abundance in the wetlands and in the fish markets did not significantly deviate from unity. When considered in terms of proportional representations in the samples of assorted size classes, a difference was observed for the lowest size class but not for any other size classes. The results of the logistic regression indicated that relative abundance did not vary significantly between the sites (wetlands and fish markets) (Table 4). However, the representations in the size classes varied significantly between the two sites, indicating that the harvest of the snails did not comply with the size class representations in the natural habitats (field data).

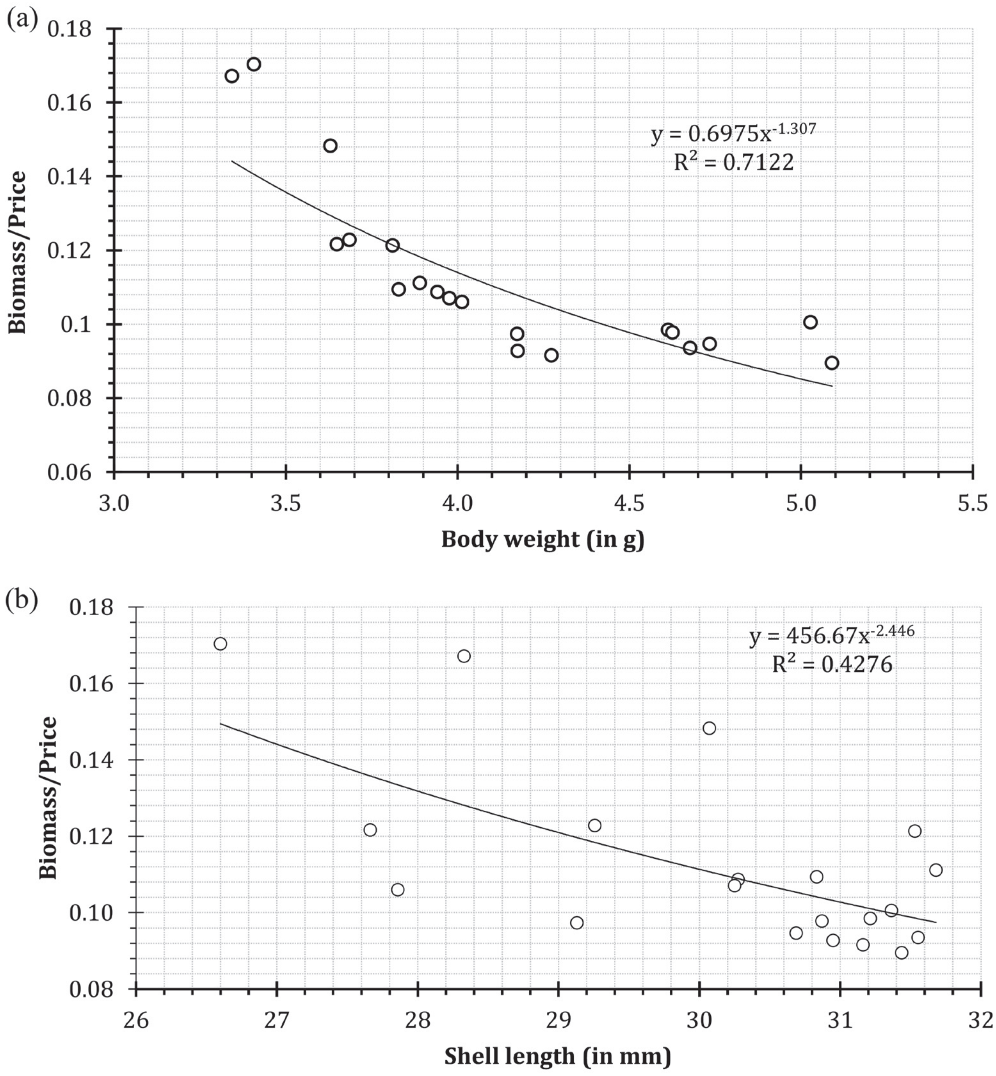

Figure 2. The standardized selling price of the viviparid snail *F. bengalensis* against body weight (a) and shell length (b) as observed in and around Kolkata and suburbs, India. Instead of the currency, the standardized prices are considered in the analysis (n = 60 different samples from different fish markets collected between 2014 and 2016). The best fit regression equations are shown in the graphs.

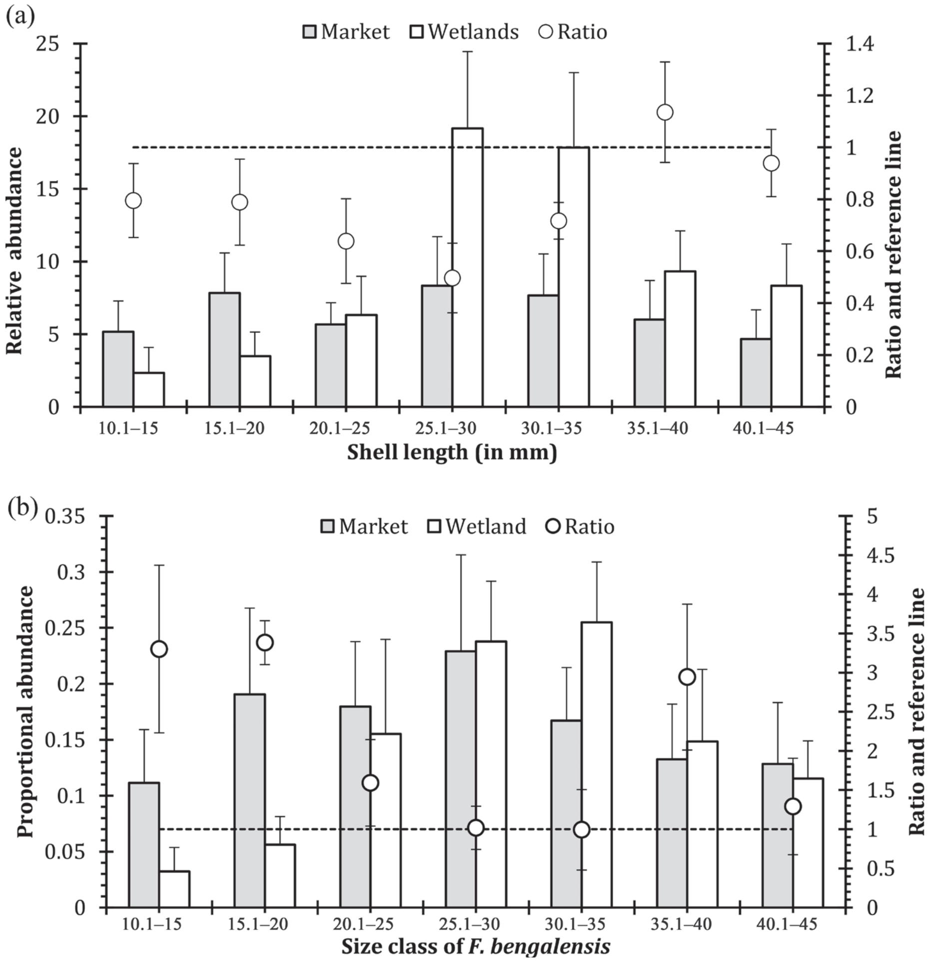

Figure 3. The relative frequency (in terms of number (a) and in terms of proportions (b)) of the different size group (shell length) of the viviparid snail *F. bengalensis* in the fish markets and in the wetlands (natural habitats) in and around Kolkata, India (n = 12 pairs of wetland and market data). Comparison of the market and the wetland data are shown through the ratio, and the dashed line shows the reference point of 1, representing no difference in the relative proportion. For each size class, the differences between the market and the wetland were not significantly different from 0, as evident from a one-tailed *t*-test.

As shown in the bar chart (Figure 4a and b) for the conventional and modified *CPUEs*, the field data were higher than the market data for both the traditional *CPUE* (Figure 4a) and modified *CPUE* (Figure 4b), irrespective of different size classes of snails. Though representation varied among size classes, they were compared aggregately for assessing the collection of a particular site. The snails from both the market and the field were segregated shell-length-wise to check their demand in the market and whether an unrestricted snail harvest for selling affected the growth of the snail population.

## DISCUSSION

Under natural conditions, size variations in snails reflect the population dynamics and the heterogeneity of the population structure. In a snail population, varied size classes are obvious for continuously breeding species with overlapping generations. Such variation in the size-class-wise representation are expected in the harvested population of the snail *F. bengalensis* similar to the one present in the natural habitats. The logistic regression equation supported no difference in the wetland and in the fish market availability of different size classes of *F. bengalensis*. However, in many instances of size-class-based differences, the variations in the field and fish market populations were observed for the snail species. The market demand for the moderate size classes may have led to the skewed harvest pattern of the species, leading to the deviations between wetland and fish market populations.

On a world-wide scale, the harvest of molluscs equals approximately 16 million tons (Cooley et al. 2012) unevenly distributed around the world. The harvest cannot be defined in a simple form with reference to the effects of the environment, economics or culture alone. Even though a large proportion of the population is undernourished, the molluscs export from India is quite significant (Cooley et al. 2012).

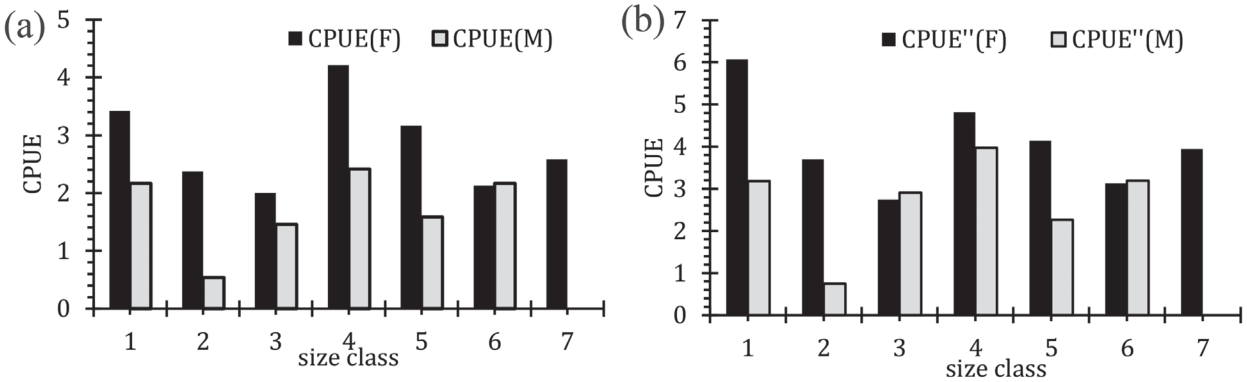

Figure 4. The abundance of the snail *F. bengalensis* was always higher in the fields than in the markets based on both traditional CPUE (a) and modified CPUE (b), which may be due to the size-based segregation of snails in markets compared to that of unbiased catch from the fields.

Table 3. The results of the statistical analysis applied on the relative abundance data (in integers and in proportion) of different size classes of the snail *F. bengalensis* from the market and the wetland (n – 12 samples each from the market and the wetlands). (i) The results of the paired *t*-test on the numerical abundance of the snails along with the results of the *t*-test to justify the deviation of the ratio (of market and wetland availability of the snail) from 1. (ii) The results of Friedman's test (*Q*-values) for multiple comparisons on the abundance of the different size classes of *F. bengalensis* in the market and the wetland, along with the results of the *t*-test to justify the deviation of the ratio (of market and wetland availability of the snail) from 1. Values in bold in the following tables are significant at $p < 0.05$ level.

(i) Based on numerical values of abundance

| Parameters | Size class of *F. bengalensis* | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10.1–15 | 15.1–20 | 20.1–25 | 25.1–30 | 30.1–35 | 35.1–40 | 40.1–45 |
| Difference | 2.833 | 4.333 | 0.667 | 10.833 | 10.167 | 3.333 | 3.667 |
| *t* (Observed value) | 0.943 | 1.491 | 0.209 | **3.516** | 1.782 | 0.879 | 0.764 |
| \|*t*\| (Critical value) | 2.571 | 2.571 | 2.571 | 2.571 | 2.571 | 2.571 | 2.571 |
| *p*-value (Two-tailed) | 0.389 | 0.196 | 0.843 | 0.017 | 0.135 | 0.420 | 0.479 |
| alpha | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |

*t*-test for the ratio against deviation from 1

| | Size class of *F. bengalensis* | | | | | | |
|---|---|---|---|---|---|---|---|
| df-11 | 10.1–15 | 15.1–20 | 20.1–25 | 25.1–30 | 30.1–35 | 35.1–40 | 40.1–45 |
| *t*-value | 0.54234 | 0.51847 | 0.8941 | 1.37465 | 1.0639 | 0.30814 | 0.16731 |

(ii) Based on the proportional abundance

| Parameters | Size class of *F. bengalensis* | | | | | | |
|---|---|---|---|---|---|---|---|
| | 10.1–15 | 15.1–20 | 20.1–25 | 25.1–30 | 30.1–35 | 35.1–40 | 40.1–45 |
| Q (Observed value) | 0.200 | 2.667 | 0.667 | 0.000 | 0.667 | 0.000 | 0.000 |
| Q (Critical value) | 3.841 | 3.841 | 3.841 | 3.841 | 3.841 | 3.841 | 3.841 |
| DF | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| *p*-value (Two-tailed) | 0.655 | 0.102 | 0.414 | 1.000 | 0.414 | 1.000 | 1.000 |
| Alpha | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 | 0.05 |

*t*-test for the ratio against deviation from 1

| | Size class of *F. bengalensis* | | | | | | |
|---|---|---|---|---|---|---|---|
| df-11 | 10.1–15 | 15.1–20 | 20.1–25 | 25.1–30 | 30.1–35 | 35.1–40 | 40.1–45 |
| *t*-value | **2.223** | **4.502** | 0.797 | 0.035 | -0.011 | 2.013 | 0.371 |

While the food value of the snails provides a necessary basis for their consumption at the local scale, the waste shells are also a useful resource for the purpose of bioremediation. The multiple uses of the snails as a food resource as well as in the sustenance of environmental quality require continued monitoring to ensure the harvest is made in parity with the natural availability. Further studies should be carried out to ensure that the harvest is made in compliance with not only size classes but also with the sex ratio of the concerned species in the local environment. Nonetheless, the observations of the present study are a pioneer effort to portray the availability and exploitation of the economically important snail species available in Kolkata, India.

Table 4. Results of binomial GLM with logit link representing the differences in the abundance of the size classes of the *F. bengalensis* as observed in the sites (wetlands and fish markets). (a) the logistic regression equations and (b) the significant test for the parameters of the model (explanatory variables; site, $x_1$ and size class, $x_2$), in the equation: abundance $(y) = 1 / (1 + \exp(-(a + b_1x_1 + b_2x_2)))$.

a)

$$\text{Abundance}_{BBE} = 1 / (1 + \exp(-(-1.95-0.110*\text{site} + + 0.09*\text{size class})))$$

b)

| *FBE* | Site ($x_1$) | Size class ($x_2$) |
|---|---|---|
| Value | -0.110 | 0.091 |
| SE | 0.083 | 0.020 |
| Wald $\chi^2$ | 1.763 | 20.753 |
| Pr > $\chi^2$ | 0.184 | < 0.0001 |

The abundance of *F. bengalensis* in markets have always been smaller than the collections from the fields. It was discussed earlier that the market demand of edible snails regulates their abundance, as the medium sized snails are preferred for selling, as they give the highest profit. The local people who directly collect the snails from water bodies, such as Rajbanshis of North Bengal (Gupta 2012), Bodo community of Assam (Kalita et al. 2020), Munda tribe of Jharkhand, Odisha and West Bengal (Rout et al. 2023) and the people of various rural parts of India (Chowdhury et al. 2015; Ghosh et al. 2016; Baghele et al. 2021; Jadhav et al. 2023) mainly depend on these edible snails for protein, vitamins and minerals, with little preference for the size or species of snails. In contrast, people buying snails from the market have a dignified choice for snail size class, which may cause the sellers to segregate the snails as per demand. Such situations may be a probable reason for medium sized snails to dominate the markets, whereas the unbiased collection of snails from fields differs significantly as shown for smaller shell length, 10.1–15 mm (*t*-score = 1.34, $p = 0.2$, df = 12) and 35.1–40 mm (*t*-score = 0.43, $p = 0.67$, df = 20) for collections from markets and fields (Supplementary file, Table 1). As the size-class-wise diversity ($H'$) was deduced for each collection, to assess the effect on *CPUE*, as described earlier ($CPUE' = CPUE * H'$), from $MSY = CPUE_{market} / CPUE_{field}$), it was calculated with both the conventional and modified *CPUE* (*CPUE* and *CPUE'*, respectively) (Supplementary file, Tables 2 and 3). The aggregated MSY was below 1 for both cases, indicating a sustainable harvest of *F. bengalensis.* From the calculation it was discerned that the *MSY* from the conventional *CPUE* for each size class was below 1, except for the first three classes and the 6th class, whereas the values of *MSY* calculated using the modified *CPUE* (*CPUE'*) were less than 1, except for the first 2 classes (Supplementary file, Table 4). The 10–20 mm long snails were in demand as deduced from the survey, firmly proving the conjecture of snail segregation, and it also can be explained by the effortless capture of medium sized snails. Larger snails are less profitable for the sellers and appeared less abundant in the catch, so they are discarded. That can be a possible explanation for the sustainable harvest of larger size classes. The size class ranging from 35.1–40 mm showed the *MSY* greater than 1 with the traditional method, whereas the *MSY* calculated considering diversity affecting the catch reduced the value below 1 (Supplementary file, Table 4), firmly stating the catch is affected by size-class-wise diversity (Sallam and El-Wakeil 2012; Tchakonté et al. 2014).

## CONCLUSION

An evaluation of the sustainable harvest of the freshwater snail *F. bengalensis* was carried out using the size-class-based abundance in the field and in fish markets. The statistical appraisal of the data indicated that the harvest pattern for the snails varied considerably, but the parity was kept between the field and market data. However, the harvest of the snails by the people of rural areas and suburbs has no restriction, and demand-wise segregation following the destruction of a huge number of snails may lead to the extinction of the population. In order to prevent that, proper guidelines for the harvest are required. The sustainable harvest of snails can be an answer to this economic and ecological want. A new approach of estimating the *MSY* of *F. bengalensis* is taken in this article, incorporating *CPUE* and size-class-wise diversity affecting the catch of snails. Diversity does not affect the catch, except for the smaller and medium sized snails. The market demand is biased towards this size. The edible snails, being an easy food option for an economically destitute section of society, bear a significant place in aquaculture and in future research for sustaining the snail population. This study opens the door for new research on the sustainable harvest of edible snails, using a novel concept of sustainable yield or *CPUE* and deducing newer methods for the calculation of harvesting. As this study has been conducted using real data from markets and fields, despite the simulating models with reasonable parameters, more research with the real-world data will give an answer to the sustainable yield of edible snails in future.

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### *Author's contribution*

Conceptualized by Gautam Aditya; Experiment execution and data collection by Joy Chakraborty; data analysis and model assessment by Gautam Aditya and Pranesh Paul; Model creation and evaluation by Gautam Aditya and Sabarni Chakraborty; manuscript preparation by Sabarni Chakraborty and Gautam Aditya.

### *Conflict of Interest*

As authors we declare no conflict of interests.

### *Data disclosure*

The calculations, if required may be provided upon authentic request.

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## SUPPLEMENTARY FILE

Table 1. Seven size classes (shell length in mm) of *F. bengalensis* collected from fish markets and freshwater wetlands, with their respective diversity (*H'*) calculated based on classical catch per unit effort (*CPUE*) and modified *CPUE* (*CPUE''*). The *CPUE''* included the diversity (*CPUE''* from equation 4) to deduce the effect of diversity on the catch for each size class. The *CPUE* and *CPUE''* were subjected to a paired *t*-test, and there was a significant difference between them, except for size classes A and F (marked in bold). The application of a paired *t*-test enabled justifying that the *CPUE* and *CPUE''*values for the concerned size class of the snail varied significantly expressing heterogeneity of the proportionate consequences by that size class.

| SIZE CLASS (shell length in mm) | *H'* | *CPUE* | *CPUE''* | *t*- score | df | *p*-value |
|---|---|---|---|---|---|---|
| A | 0.164575 | 0.125 | 0.118677 | | | |
| 10.1–15 | 0.349232 | 0.375 | 0.251835 | **1.34** | **12** | **0.2** |
| MEAN | 0.234691 | 0.25 | 0.169239 | | | |
| 12.55 | 0.346574 | 0.541667 | 0.249918 | | | |
| | 0.269476 | 0.458333 | 0.194322 | | | |
| | 0.070931 | 0.041667 | 0.051149 | | | |
| | 0.132419 | 0.083333 | 0.095489 | | | |
| B | 0.338385 | 0.5 | 0.206415 | | | |
| 15.1–20 | 0.350751 | 0.708333 | 0.213958 | 2.56 | 14 | 0.022632 |
| MEAN | 0.116114 | 0.083333 | 0.070829 | | | |
| 17.55 | 0.364004 | 0.5 | 0.222042 | | | |
| | 0.197304 | 0.166667 | 0.120355 | | | |
| | 0.242506 | 0.375 | 0.147928 | | | |
| | 0.257544 | 0.291667 | 0.157102 | | | |
| | 0.2356 | 0.208333 | 0.143716 | | | |
| C | 0.269949 | 0.291667 | 0.134674 | | | |
| 20.1–25 | 0.367504 | 0.208333 | 0.183344 | 2.21 | 18 | 0.040466 |
| MEAN | 0.321888 | 0.291667 | 0.160586 | | | |
| 22.55 | 0.184424 | 0.166667 | 0.092007 | | | |
| | 0.358858 | 0.458333 | 0.17903 | | | |
| | 0.191339 | 0.25 | 0.095457 | | | |
| | 0.207076 | 0.166667 | 0.103308 | | | |
| | 0.332942 | 1.708333 | 0.166101 | | | |
| | 0.340452 | 0.5 | 0.169847 | | | |
| | 0.34956 | 0.666667 | 0.174392 | | | |
| D | 0.367871 | 0.791667 | 0.142652 | | | |
| 25.1–30 | 0.333329 | 0.291667 | 0.129258 | 3.79 | 22 | 0.000995 |
| MEAN | 0.101581 | 0.75 | 0.039391 | | | |
| 27.55 | 0.363126 | 0.208333 | 0.140812 | | | |
| | 0.266862 | 0.208333 | 0.103483 | | | |
| | 0.367601 | 0.625 | 0.142547 | | | |
| | 0.351316 | 0.041667 | 0.136233 | | | |
| | 0.08065 | 1.583333 | 0.031274 | | | |
| | 0.367785 | 0.5 | 0.142619 | | | |
| | 0.291446 | 0.416667 | 0.113016 | | | |
| | 0.348419 | 0.541667 | 0.135109 | | | |
| | 0.362439 | 0.791667 | 0.140546 | | | |
| E | 0.328593 | 0.458333 | 0.090911 | | | |
| 30.1–35 | 0.28797 | 0.083333 | 0.079672 | 3.58 | 24 | 0.001499 |
| MEAN | 0.163554 | 0.083333 | 0.04525 | | | |
| 32.55 | 0.325973 | 0.5 | 0.090186 | | | |
| | 0.095726 | 0.041667 | 0.026484 | | | |
| | 0.367225 | 0.75 | 0.101599 | | | |
| | 0.170566 | 0.208333 | 0.04719 | | | |
| | 0.364004 | 0.75 | 0.100708 | | | |
| | 0.359375 | 0.583333 | 0.099427 | | | |
| | 0.364881 | 1.75 | 0.10095 | | | |
| | 0.266862 | 0.416667 | 0.073832 | | | |
| | 0.363682 | 0.666667 | 0.100619 | | | |
| | 0.317851 | 0.5 | 0.087939 | | | |

| SIZE CLASS (shell length in mm) | *H'* | *CPUE* | *CPUE''* | *t*- score | df | *p*-value |
|---|---|---|---|---|---|---|
| F | 15 | 0.041667 | 2.483333 | | | |
| 35.1–40 | 0.33735 | 0.333333 | 0.05585 | **0.43** | **20** | **0.67** |
| MEAN | 0.349757 | 0.625 | 0.057904 | | | |
| 37.55 | 0.338385 | 0.5 | 0.056022 | | | |
| | 0.242506 | 0.375 | 0.040148 | | | |
| | 0.186439 | 0.166667 | 0.030866 | | | |
| | 0.357573 | 0.916667 | 0.059198 | | | |
| | 0.104451 | 0.125 | 0.017292 | | | |
| | 0.179033 | 0.208333 | 0.02964 | | | |
| | 0.29057 | 0.333333 | 0.048105 | | | |
| | 0.294282 | 0.416667 | 0.04872 | | | |
| G | 0.197304 | 0.041667 | 0.010742 | | | |
| 40.1–45 | 0.367008 | 0.5 | 0.019982 | 4.47 | 20 | 0.000236 |
| MEAN | 0.070008 | 0.041667 | 0.003812 | | | |
| 42.55 | 0.341138 | 0.375 | 0.018573 | | | |
| | 0.225174 | 0.208333 | 0.012259 | | | |
| | 0.291988 | 0.541667 | 0.015897 | | | |
| | 0.32803 | 0.5 | 0.017859 | | | |
| | 0.307381 | 0.75 | 0.016735 | | | |
| | 0.236978 | 0.333333 | 0.012902 | | | |
| | 0.127007 | 0.083333 | 0.006915 | | | |
| | 0.20304 | 0.208333 | 0.011054 | | | |
| A | 0.164575 | 0.125 | 0.118677 | | | |
| 10.1–15 | 0.349232 | 0.375 | 0.251835 | **1.34** | **12** | **0.2** |
| MEAN | 0.234691 | 0.25 | 0.169239 | | | |
| 12.55 | 0.346574 | 0.541667 | 0.249918 | | | |
| | 0.269476 | 0.458333 | 0.194322 | | | |
| | 0.070931 | 0.041667 | 0.051149 | | | |
| | 0.132419 | 0.083333 | 0.095489 | | | |
| B | 0.338385 | 0.5 | 0.206415 | | | |
| 15.1–20 | 0.350751 | 0.708333 | 0.213958 | 2.56 | 14 | 0.022632 |
| MEAN | 0.116114 | 0.083333 | 0.070829 | | | |
| 17.55 | 0.364004 | 0.5 | 0.222042 | | | |
| | 0.197304 | 0.166667 | 0.120355 | | | |
| | 0.242506 | 0.375 | 0.147928 | | | |
| | 0.257544 | 0.291667 | 0.157102 | | | |
| | 0.2356 | 0.208333 | 0.143716 | | | |
| C | 0.269949 | 0.291667 | 0.134674 | | | |
| 20.1–25 | 0.367504 | 0.208333 | 0.183344 | 2.21 | 18 | 0.040466 |
| MEAN | 0.321888 | 0.291667 | 0.160586 | | | |
| 22.55 | 0.184424 | 0.166667 | 0.092007 | | | |
| | 0.358858 | 0.458333 | 0.17903 | | | |
| | 0.191339 | 0.25 | 0.095457 | | | |
| | 0.207076 | 0.166667 | 0.103308 | | | |
| | 0.332942 | 1.708333 | 0.166101 | | | |
| | 0.340452 | 0.5 | 0.169847 | | | |
| | 0.34956 | 0.666667 | 0.174392 | | | |
| D | 0.367871 | 0.791667 | 0.142652 | | | |
| 25.1–30 | 0.333329 | 0.291667 | 0.129258 | 3.79 | 22 | 0.000995 |
| MEAN | 0.101581 | 0.75 | 0.039391 | | | |
| 27.55 | 0.363126 | 0.208333 | 0.140812 | | | |
| | 0.266862 | 0.208333 | 0.103483 | | | |
| | 0.367601 | 0.625 | 0.142547 | | | |
| | 0.351316 | 0.041667 | 0.136233 | | | |
| | 0.08065 | 1.583333 | 0.031274 | | | |
| | 0.367785 | 0.5 | 0.142619 | | | |
| | 0.291446 | 0.416667 | 0.113016 | | | |
| | 0.348419 | 0.541667 | 0.135109 | | | |
| | 0.362439 | 0.791667 | 0.140546 | | | |

| SIZE CLASS (shell length in mm) | *H'* | *CPUE* | *CPUE''* | *t*- score | df | *p*-value |
|---|---|---|---|---|---|---|
| E | 0.328593 | 0.458333 | 0.090911 | | | |
| 30.1–35 | 0.28797 | 0.083333 | 0.079672 | 3.58 | 24 | 0.001499 |
| MEAN | 0.163554 | 0.083333 | 0.04525 | | | |
| 32.55 | 0.325973 | 0.5 | 0.090186 | | | |
| | 0.095726 | 0.041667 | 0.026484 | | | |
| | 0.367225 | 0.75 | 0.101599 | | | |
| | 0.170566 | 0.208333 | 0.04719 | | | |
| | 0.364004 | 0.75 | 0.100708 | | | |
| | 0.359375 | 0.583333 | 0.099427 | | | |
| | 0.364881 | 1.75 | 0.10095 | | | |
| | 0.266862 | 0.416667 | 0.073832 | | | |
| | 0.363682 | 0.666667 | 0.100619 | | | |
| | 0.317851 | 0.5 | 0.087939 | | | |
| F | 15 | 0.041667 | 2.483333 | | | |
| 35.1–40 | 0.33735 | 0.333333 | 0.05585 | **0.43** | **20** | **0.67** |
| MEAN | 0.349757 | 0.625 | 0.057904 | | | |
| 37.55 | 0.338385 | 0.5 | 0.056022 | | | |
| | 0.242506 | 0.375 | 0.040148 | | | |
| | 0.186439 | 0.166667 | 0.030866 | | | |
| | 0.357573 | 0.916667 | 0.059198 | | | |
| | 0.104451 | 0.125 | 0.017292 | | | |
| | 0.179033 | 0.208333 | 0.02964 | | | |
| | 0.29057 | 0.333333 | 0.048105 | | | |
| | 0.294282 | 0.416667 | 0.04872 | | | |
| G | 0.197304 | 0.041667 | 0.010742 | | | |
| 40.1–45 | 0.367008 | 0.5 | 0.019982 | 4.47 | 20 | 0.000236 |
| MEAN | 0.070008 | 0.041667 | 0.003812 | | | |
| 42.55 | 0.341138 | 0.375 | 0.018573 | | | |
| | 0.225174 | 0.208333 | 0.012259 | | | |
| | 0.291988 | 0.541667 | 0.015897 | | | |
| | 0.32803 | 0.5 | 0.017859 | | | |
| | 0.307381 | 0.75 | 0.016735 | | | |
| | 0.236978 | 0.333333 | 0.012902 | | | |
| | 0.127007 | 0.083333 | 0.006915 | | | |
| | 0.20304 | 0.208333 | 0.011054 | | | |

Table 2. As the intrinsic growth rate ($r$) and carrying capacity ($k$) for small indigenous snails/fishes cannot be deduced, as they come into the rice fields with rain water or flood, their population in that particular place of collection becomes finite. So, the classical $MSY = \frac{rk}{4}$ has been modified to a simpler form, $MSY = \frac{CPUE_{market}}{CPUE_{field}}$. If the MSY is equal to 1, the resource is at *MSY*, and if less than 1, the catch is sustainable. If the *MSY* is more than 1, then catch should be lowered to sustain the resource. Here, the *MSY* is less than 1, declaring the sustainable catch.

| Market | | Field | | |
|---|---|---|---|---|
| *H'* | *CPUE* | *H'* | *CPUE* | *MSY* |
| 1.46937 | 2.16667 | 1.77598 | 3.41667 | 0.63415 |
| 1.38341 | 0.54167 | 1.55826 | 2.375 | 0.22807 |
| 1.99136 | 1.45833 | 1.37269 | 2 | 0.72917 |
| 1.64409 | 2.41667 | 1.1445 | 4.20833 | 0.57426 |
| 1.42659 | 1.58333 | 1.30726 | 3.16667 | 0.5 |
| 1.47466 | 2.16667 | 1.47013 | 2.125 | 1.01961 |
| | | 1.52717 | 2.58333 | |
| Average | 1.72222 | | 2.83929 | |
| MSY | 0.60657 | | | |

Table 3. To check the effect of the size class diversity on $CPUE$, an equation was proposed, modified $CPUE$ ($CPUE''$) = $CPUE * H'$, and the same concept of $MSY$ described in Table 2 was applied to check. No significant difference was found between these two $MSY$ ($p = 0.64$, df = 10).

| Market | | Field | | |
|---|---|---|---|---|
| $H'$ | $CPUE''$ | $H'$ | $CPUE''$ | $MSY'$ |
| 1.46937 | 3.18364 | 1.77598 | 6.06793 | 0.5247 |
| 1.38341 | 0.74935 | 1.55826 | 3.70088 | 0.2025 |
| 1.99136 | 2.90407 | 1.37269 | 2.74539 | 1.0578 |
| 1.64409 | 3.97322 | 1.1445 | 4.81643 | 0.8249 |
| 1.42659 | 2.25876 | 1.30726 | 4.13966 | 0.5456 |
| 1.47466 | 3.1951 | 1.47013 | 3.12403 | 1.0227 |
| | | 1.52717 | 3.94519 | |
| Average | 2.71069 | | 4.07707 | |
| MSY | 0.66486 | | | |

Table 4.The size-class-wise $MSY$ from traditional and modified $CPUE$. The $MSY$ values greater than 1 are highlighted in bold.

| Size classshell length (in mm) | $CPUE_{market}$ | $CPUE_{field}$ | $MSY$ | $CPUE'_{market}$ | $CPUE'_{field}$ | $MSY'$ |
|---|---|---|---|---|---|---|
| A | | | | | | |
| 10.1–15 | 1.291667 | 0.583333 | **2.214286** | 0.983991 | 0.34096 | **2.885941** |
| MEAN | | | | | | |
| 12.55 | | | | | | |
| B | | | | | | |
| 15.1–20 | 1.958333 | 0.875 | **2.238095** | 0.8336 | 0.448746 | **1.857621** |
| MEAN | | | | | | |
| 17.55 | | | | | | |
| C | | | | | | |
| 20.1–25 | 0.749642 | 0.709105 | **1.057166** | 1.416667 | 3.291667 | 0.43038 |
| MEAN | | | | | | |
| 22.55 | | | | | | |
| D | | | | | | |
| 25.1–30 | 0.555596 | 0.841345 | 0.660366 | 2.25 | 4.5 | 0.5 |
| MEAN | | | | | | |
| 27.55 | | | | | | |
| E | | | | | | |
| 30.1–35 | 0.434101 | 0.610664 | 0.710867 | 1.916667 | 4.875 | 0.393162 |
| MEAN | | | | | | |
| 32.55 | | | | | | |
| F | | | | | | |
| 35.1–40 | 2.653109 | 0.27397 | **9.683938** | 1.5 | 2.541667 | 0.590164 |
| MEAN | | | | | | |
| 37.55 | | | | | | |
| G | | | | | | |
| 40.1–45 | 0.065368 | 0.081363 | 0.803408 | 1.166667 | 2.416667 | 0.482759 |
| MEAN | | | | | | |
| 42.55 | | | | | | |