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# Harnessing the Potential of Naturally-stabilized Earthen Ponds for Hill Aquaculture: A Demonstration Using Fish Species Combinations in Meghalaya

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***Authors' contributions***

*This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.*

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## ABSTRACT

Aquaculture plays a pivotal role in sustaining livelihoods in the hilly regions of India. However, these areas face challenges in aquaculture production due to prolonged cold climates and suboptimal water temperatures. This study aimed to develop a low-input aquaculture system tailored for hilly

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conditions in Meghalaya, Northeast India, by employing naturally-stabilized earthen ponds. Ranging in area from 700 to 1500 m2 and with a depth of 1.5 to 2m, these ponds were stocked with fish of different feeding niches at a density of 5000 fish per hectare, with the following compositions: 20% Catla, 40% Rohu, and 40% Gonia in Pond 1; 20% Catla, 40% Rohu, and 40% Common carp in Pond 2; and 20% Catla, 40% Rohu, 20% Gonia, and 20% Common carp in Pond 3. The average size was 28.4±1.8 g for Catla, 7.5±0.4 g for Rohu, 7.6±0.5 g for Gonia, and 10.8±1.3 g for Common carp. The culture duration spanned 8 months, with the initial two months involving feeding fish with commercial feed and the subsequent 6 months with farm-made feed at 2% body weight. Monthly assessments of water quality parameters and bi-monthly evaluations of fish growth attributes were conducted. Analysis of water temperature revealed suboptimal average temperatures ranging from 19.5°C to 20.2°C. Fish production attributes at the end of 8-month was found to be better in Pond 2 (survival 83.2%; biomass 1227.5 kg/ha; FCR 1.53), followed by Pond 3 (survival 82.3%; biomass 1114.8 kg/ha; FCR 1.60) and Pond 1 (survival 81.1%; biomass 998.7 kg/ha; FCR 1.64). Ponds containing Common carp exhibited lower biomass, potentially due to their aggressive feeding behavior leading to competition with co-habiting fishes. It is concluded that naturally-stabilized earthen ponds in hilly areas could serve as a valuable resource for hill aquaculture. However, optimizing productivity requires appropriate fish combinations to minimize inter-specific competitions.

*Keywords: Composite fish culture; naturally stabilized earthen ponds; hill aquaculture; fish growth; survival.*

## 1. INTRODUCTION

Fish play a vital role in the hilly areas of Northeastern Region (NER) of India, celebrated for its abundant natural resources and biodiversity hotspots [1]. Beyond being a culinary delight, fish is a cornerstone of livelihoods, particularly in hill communities where it is deeply rooted in cultural traditions [2]. In the rugged terrain of the region, where sustaining life requires greater energy expenditure, fish stands out as a crucial source of high-quality protein, essential fatty acids, vitamins, and minerals. This nutritional contribution is particularly critical given the prevalence of malnutrition and dietary deficiencies in the region [3]. For generations, fish has been a pillar of nutritional security for NER residents, highlighting its enduring significance in the socio-economic fabric of the region.

Fisheries play a crucial role in ensuring rural livelihood security in NER, encompassing both capture and culture-based practices. Despite facing numerous challenges, such as rugged terrain, limited availability of suitable land for constructing scientifically designed fish ponds with proper inlet and outlet facilities, water scarcity during the dry season, the unsuitability of most fish species for hill climates, frequent disease outbreaks in fish due to the prolonged cold climate and their suppressed immune and disease resistance mechanisms, inadequate infrastructures, road connectivity, and transportation facilities hindering the procurement of inputs at affordable prices and the disposal of fish to potential markets with minimum floor prices (MFP), the sector remains vital as a livelihood for tens of thousands of people due to its importance in the socio-economic fabric of the region [2].

Pond-based fish farming, in particular, is common in the NER and has gained momentum in recent years, especially in the post-COVID era, due to increased demand for fresh fish from local communities, offering potential scopes and opportunities for additional income generation and employment. However, the pond resources in the hill ecosystems of the NER face several challenges.

The pond resources in the NER are primarily naturally stabilized with earthen basins and face several challenges, including heavy silt accumulation from runoff water, eutrophication, drastic diurnal and dial variations in water quality parameters, particularly temperature and dissolved oxygen (DO), difficulty in complete dewatering, formation of sharp thermocline, heavy seepage, and percolation loss [4]. Despite being rich with natural fish food organisms like plankton and benthos, these challenges have largely hindered their effective utilization for fish production. Currently, no suitable technologies are available for exploitation of such ponds for scientific fisheries.

Therefore, in this study, we evaluated some ponds of similar kinds under the agro-climatic conditions of Meghalaya, NER, where more than 99% of the population is active fish consumers. We evaluated different fish species compositions, including bottom-dwelling, surface-feeding, and column-feeding fish with an aim to develop a low-input aquaculture system tailored for hilly conditions by employing naturally-stabilized earthen ponds. Our focus was on fish like Common carp (*Cyprinus carpio*) and Gonia (*Labeo gonius*), which are bottom-dwelling and well-suited to the hill climate of Meghalaya. The aim of our study was to develop a fish production system that suits the rugged hill pond conditions and produces enough fish for sustaining associated livelihoods.

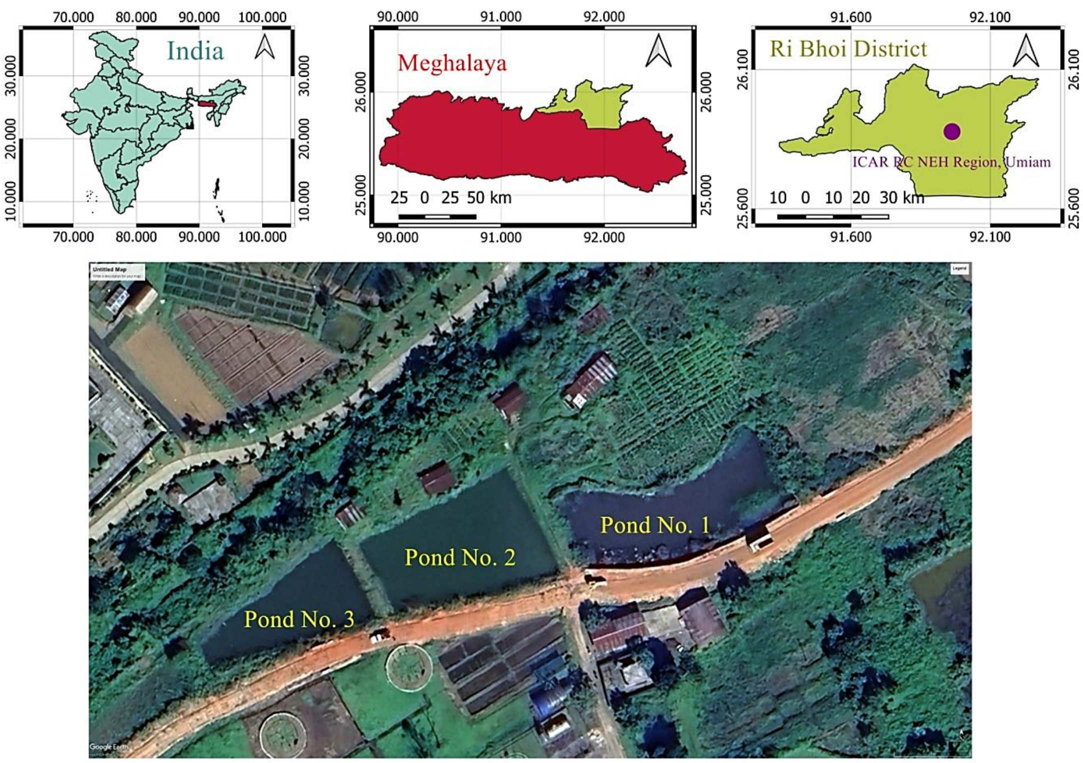
## 2. MATERIALS AND METHODS

### 2.1 Experimental Site

The study was carried out in Umiam, Meghalaya (GPS coordinates: 25°33'N, 91°53'E; elevation: 950 m above mean sea level) employing three ponds having naturally stabilized earthen basins. The size of pond 1 was 1500 m$^2$, pond 2 was 1000 m$^2$, and pond 3 was 700 m2. Pond 2 was almost rectangular in shape, while ponds 1 and 3 were trapezoidal. The depth of pond 1 varied from 1.5 to 2 meters, while the depth of the other two varied from 1 to 1.5 meters. These ponds were without proper inlet and outlet, contour and basin configuration, an important criterion for scientifically designed fish ponds. These ponds were filled with rainfall and runoff waters which are mainly in use for life-saving irrigation purposes in the agro-forestry farms rather than fish culture.

### 2.2 Pond Management and Fish Stocking

Before commencing the study, the area surrounding the ponds was cleared of jungles, bushes, and hanging tree branches. Subsequently, the old fish stocks were removed from the ponds through repeated netting operations. Water pH analysis was then conducted, and liming material applied at a rate of 250 kg after soaking overnight in water. After about a week, when the water color changed from light brown to green or greenish, the ponds were stocked with fish seeds. Manure application was avoided to inhibit eutrophication, as analysis of composite pond sediments revealed richness in nutrients.




**Map 1. Map showing the experimental site**

**Table 1. Different fish species compositions followed**

| Pond No. | 1 | 2 | 3 |
|---|---|---|---|
| Area ($m^2$) | 1500 | 1000 | 750 |
| Fish stocked (numbers) | 750 | 500 | 350 |
| Fish species composition | Catla: 20%<br>Rohu: 40%<br>Gonia: 40% | Catla: 20%<br>Rohu: 40%<br>Common Carp: 40% | Catla: 20%<br>Rohu: 40%<br>Gonia: 20%<br>Common Carp: 20% |

The fish seeds were procured from our Fisheries Research Farm, ICAR, Meghalaya. They were stocked in the morning hours (9 to 10 AM) and properly sanitized by dipping in a potassium permanganate (KMnO4) solution at a concentration of 5 $mg^{l-1}$ for 30 seconds before stocking into the ponds. A stocking density (number of fish /ha) of 5000 was followed for fish seeds, which was lower than the general recommendation of 10,000 in composite culture [5]. The different species compositions followed for fish (treatments) are presented in Table 1. Across the treatments, the proportion of surface-feeding fish (Catla) were stocked at 20%, whereas, the proportion of column-feeding fish (Rohu) were stocked at 40%, and the proportion of bottom-dwelling fish (Gonia and Common carp) stocked at 40%. In pond 3, where both Gonia and Common carp were stocked, the ratio between the two was maintained at 1:1 to study the interaction between them. At the time of stocking, the size of the seeds was recorded by sampling 10 fish for each species. Total length was measured to the nearest centimeter (cm) with a measuring ruler, and wet weight was measured to the nearest 0.1 gram (g). The average size was estimated to be 28.4±1.8 g for Catla, 7.5±0.4 g for Rohu, 7.6±0.5 g for Gonia, and 10.8±1.3 g for Common carp.

### 2.3 Supplementary Feeding and Other Management

One day after stocking fish seeds, we began providing them with supplementary feeds. A mixture of rice bran and mustard oil cake in a 1:1 ratio, as well as commercial pellet feed, was used to minimize feed costs. The feed ingredients were procured from the local market in Shillong, Meghalaya. The commercial feed had a crude protein (CP) content of 24.2%, while the farm-made feed, prepared by mixing rice bran and mustard oil cake, had a CP content of 18.8%.

During the initial 2 months of culture, we provided commercial pellet feed to ensure that small fish received adequate nutrition. From the third month onwards, we fed the fish with farm-made feed. The feeding rate was maintained at 2% throughout the 8-month study period, which was lower than the generally recommended 4-5% in composite culture. Feeding was primarily done in the morning hours (9 to 10 AM), and the feeding rate was adjusted according to fish biomass when transitioning from commercial feed to farm-made feed. We minimized the application of manures/fertilizers in the ponds until the density of plankton dropped to ≤0.5 ml/50 liters of water. At that point, we applied semi-dried cattle manure at a dose of 10 MT/ha to enhance plankton productivity, aiming to maintain plankton productivity > 1m/50 liters throughout the culture period.

### 2.4 Assessment of Water Quality Parameters

The water quality parameters of the ponds were studied bi-monthly (9:00-10:00 AM) for temperature, DO, total dissolved solids (TDS), pH, and total ammonia. Water temperature was tested with a digital thermometer, DO with a portable DO meter (Make: Lutron PDO-519), pH with a portable pH meter (Make: Eutech Instruments PCSTestr 35), TDS with a portable TDS meter (Make: TDS-3), and ammonia using a kit (Make: API, USA).

Plankton analysis (quantitative) was conducted by filtering 50 liters of water from each pond through a bolting silk net (No. 25, mesh 34µ). The filtered water was then transferred to a measuring cylinder, and the final volume was adjusted to 10 ml. To preserve the plankton samples, 2-3 drops of 10% neutral buffered formalin (NBF) were added to each sample bottle. The preserved samples were transported to the laboratory for enumeration under a compound microscope. The drop count method, as described by Jhingran et al. [6], was used for plankton enumeration. In this method, a known volume of the preserved water sample was placed in a counting chamber, and the number of plankton organisms in a specified number of drops was counted under the microscope. This count was then used to estimate the plankton density in the original water sample.

### 2.5 Pond Sediment Nutrient Analysis

At the end of the experiment, soil samples were gathered from all ponds. Composite samples were formed for each pond by combining soil from 4-5 sites within each pond. These composite samples were subsequently analyzed for nitrogen (De, 1962), phosphorus (Troug, 1930), organic carbon (Walkley and Black, 1934), and potassium using the Flame photometric extraction method.

### 2.6 Fish Growth Assessment

Ten fish (for each fish species) were bi-monthly sampled from each pond using a cast net. Then, their length (total) and weight (wet) were estimated. The total length of individual fish was measured nearest to one cm with a measuring scale, and wet weight was measured nearest to 0.1 g with an analytical balance (Make: Shimadzu, ATX224). At the end of the study (January 20, 2022 to September 2022; 8 months), all fish were harvested by repeated netting and counted for calculating their survival rate in different species compositions.

The following methods were used for estimating different fish growth parameters:

- Survival (%) = [Number of fish recovered / Number of fish stocked] × 100
- Specific growth rate (SGR, %/day) = [(ln Final weight – ln Initial weight) / culture duration ] × 100
- Average daily gain (ADG, g/fish) = (Size of fish at harvesting time – size of fish at stocking time) / culture duration
- Fish biomass (kg/pond) = Number of fish recovered from pond × average weight of fish
- Feed conversion ratio (FCR) = Total amount of feed supplemented to fish (g) / Fish biomass obtained (g)

### 2.7 Assessment of Fish Condition

The length and weight data of the experimental fish were plotted against each other in Microsoft Excel. Using the scatter plot, linear regression equations were derived. An assumption about the condition of fish under different species compositions treatments was then made based on the value of 'b' in the regression line. For example, if the regression line between the length and weight data of fish was represented as Y=a+bX, where Y= dependent variable (weight), X = independent variable (length), then the value of 'a' indicated the intercept of the regression line, and the value of 'b' indicated the slope of the regression line. This slope of the regression line was nothing but the condition of the fish. A slope of b = 3 indicated isometric growth in fish; b = < 3 indicated negative allometric growth, and b = > 3 indicated positive allometric growth in fish [7]. It was always assumed that the fish were under ideal conditions in their production systems.

### 2.8 Data Analysis

The data were analyzed descriptively using Microsoft Excel's data analysis tools. Central tendency measures, such as means and standard deviations, were calculated for the various parameters assessed, including water quality parameters, fish growth attributes, and production metrics. Linear regression analyses were performed to determine the condition factor of the fish.

## 3. RESULTS AND DISCUSSION

### 3.1 Water Quality Parameters

The data on water quality parameters is presented in Table 2. In the study period (January-September), the average air temperature was 22.3°C while average water temperature eas 20.2°C in pond 1 to 19.5°C in pond 2 to 19.6°C in pond 3 (Table 2). The ideal temperature for fish cultures hardly remained for 3-4 months (May to August). This variability signals fluctuating environmental conditions that could impact the thermal dynamics of the ponds.

Water temperature plays a crucial role in fish culture; it is a very critical factor of production upon which overall water quality and fish growth heavily rely [8,9,10]. Based on the observed temperature ranges, it is could be said that a suboptimal condition was prevailed for fish in this study which aligns with earlier studies conducted in Meghalaya [5]. Das et al. [11] further reported that during the winter months, besides prevailing a prolonged cold climate, water temperature rapidly drops from 22°C during the day to as low as 6°C at night. Such drastic dial variations lead to acute stress in fish, resulting to decreased feed intake, stunted growth, and increased susceptibility to diseases [8]. In these situations, it is advised for adopting appropriate measures such as farming fish which are tolerant to cold climate, feeding fish with a quality diet and containing growth promoting or immunity enhancing factors (turmeric powder, withania root powder, etc) and additionally, breaking the thermoclines formed in the water bodies periodically by aeration, and implementing thermal insulation in water through green housing techniques.

The DO levels were suitable for fish culture [12]. Pond 3 stood out with the highest average DO level at 6.1 ppm, indicating excellent oxygenation in water. This was attributed to the sustained production of plankton, which significantly contributed to maintaining these higher DO levels. Plankton, through photosynthesis, generate oxygen. Additionally, minimal manure application was practiced in the study due to the ponds' richness in organic carbon and inorganic nutrients. This approach helped prevent issues like eutrophication, ensuring stable DO levels across the ponds. Furthermore, the water bodies' location, situated between two hills, might have promoted higher air circulation and the mixing of atmospheric air with water. This natural ventilation likely contributed to the overall optimal DO levels observed in the study.

The pH level plays a pivotal role in fish culture, directly influencing fish health and growth. Maintaining optimal pH levels is essential for ensuring the well-being and survival of fish. Typically, water with a pH range of 7.5 to 8.5 is preferred, while soil with a pH range of 6.5 to 7.5 is considered ideal. The pH of water is intricately linked to soil pH, underscoring the interdependence of these variables in aquaculture systems. In our study, we observed a range of average pH levels in the ponds, from 6.8 in pond 1 to 6.4 in pond 2 to 6.5 in pond 3. Although these findings align with earlier research [13], the slightly acidic pH levels may stem from the presence of organic matter and ongoing decomposition processes in these nutrient-rich hill ponds. Monitoring and regulating pH levels are vital in fish culture systems, as prolonged exposure to acidic conditions can stress fish and heighten their susceptibility to health issues. Given that soils in Northeast India tend to be predominantly acidic, posing a significant challenge to fish culture, higher doses of lime may be necessary to rectify pH imbalances. In our study, we applied lime at a rate of 250 kg/ha to address pH concerns. However, considering the persistently acidic pH in the ponds, we advocate for a higher lime application rate in future studies conducted in these regions.

The TDS level is a critical factor in aquaculture. High TDS levels indicate pollution or excessive nutrient loading, which can stress fish, while low TDS indicates a lack of essential minerals in water necessary for fish growth. In our study, the TDS levels were within the acceptable range for fish culture, but they were higher than values reported earlier [5]. This suggests that there may be slight pollution or higher nutrient loading in the water. Correcting TDS levels in hill aquaculture could be challenging but is essential for maintaining a healthy environment for fish. Measures such as controlling excessive runoff, balancing nutrient levels in water, and improving water circulation through methods like oxygenation can help mitigate TDS-related issues.

Plankton are crucial as a natural food source for fish in aquaculture production systems. In this study, the mean plankton density (ml/50 L) varied from 1.1-1.3, all within the optimal range for fish culture [14]. The average plankton density recorded highest in pond 1, while lowest in pond 3. This indicates that the ponds sustained optimal plankton productivity throughout the culture period. The reasons for sustained plankton production could be the nutrient-rich hill pond environment, need-based manuring, suitable water parameters, and the absence of adverse conditions such as eutrophication.

**Table 2. The ponds' water quality parameters (mean value with range in the brackets)**

| Parameter | Pond 1 | Pond 2 | Pond 3 | Ideal range |
|---|---|---|---|---|
| Air temperature (°C) | 22.3 ± 6.2 | | | 25-30 |
| Water temperature (°C) | 20.2 ± 5.7 | 19.5 ± 4.1 | 19.6 ± 4.7 | 25-30 |
| DO (ppm) | 5.8 ± 2.1 | 5.5 ± 2.0 | 6.1 ± 2.0 | ≥5 |
| TDS (ppm) | 250 ± 15 | 270 ± 18 | 260 ± 16 | ≤500 |
| pH | 6.8 ± 0.6 | 6.4 ± 1.3 | 6.5 ± 1.5 | 7.5-8.5 |
| Ammonia (ppm) | 0.2±0.21 | 0.3±0.18 | 0.25 ±0.22 | <1.0 |
| Plankton (ml/50L) | 1.3 ± 0.8 | 1.2 ± 0.6 | 1.1 ± 0.8 | >1.0 |

## 3.2 Pond Sediment Quality

The analysis of pond sediment nutrient content revealed high levels of organic carbon, nitrogen, phosphorus, and potassium across all three ponds. Pond 3 exhibited the highest organic carbon content (2.37%), followed by Pond 1 (2.02%) and Pond 2 (1.76%). Similarly, Pond 3 had the highest nitrogen (344.96 Kg/ha) and phosphorus (4.93 Kg/ha) levels, while Pond 2 had the lowest levels of these nutrients (288.51 Kg/ha nitrogen and 4.03 Kg/ha phosphorus). Potassium levels were highest in Pond 1 (180.88 Kg/ha) and lowest in Pond 2 (162.80 Kg/ha). The reasons for such high soil quality are that the ponds were formed through natural processes rather than being purposefully excavated and lined, thus accumulating nutrients and organic matter from various sources over time [15]. Additionally, being situated in the valley of the agro-forestry farm, they might be regularly receiving nutrient-rich runoff from the surrounding agricultural areas and forests.

The relatively high organic carbon content coupled with elevated levels of essential nutrients across all three ponds likely contributed to the sustained plankton productivity which played a crucial role in maintaining optimal dissolved oxygen levels and overall ecosystem productivity within the ponds [16]. This aligns with the observed fish growth performance, particularly in Pond 2, which exhibited the highest biomass production of 1227.5 kg/ha, survival rate of 83.2%, and lowest feed conversion ratio of 1.53. Pond 2 potentially benefited from the elevated nutrient levels and associated aquatic productivity.

## 3.3 Fish Growth and Production

The fish growth parameters are illustrated in Table 3. The fish size at harvesting, which is a direct indicator of growth performance, varied among the ponds. Catla and Rohu exhibited larger final sizes in Pond 2 compared to Pond 1 and 3, suggesting that the conditions in Pond 2 were more favorable for their growth. On the other hand, Gonia and Common Carp had smaller final sizes in Pond 3 compared to their size in other ponds (Gonia in pond 1 and Common Carp in pond 2), indicating less optimal growth conditions in Pond 3 for these species.

The SGR, which measures the percentage increase in body weight per day, followed a similar trend. Catla and Rohu displayed slightly higher SGRs in Pond 2, indicating faster relative growth rates compared to Ponds 1 and 3. Conversely, Gonia and Common Carp exhibited lower SGRs in Pond 3, reflecting slower relative growth rates in this treatment.

The ADG, which represents the absolute increase in body weight per day, also showed variations across the ponds and fish species. Catla and Rohu had higher ADGs in Pond 2, suggesting faster daily weight gain compared to Ponds 1 and 3. In contrast, Gonia and Common Carp exhibited lower ADGs in Pond 3, indicating slower daily weight gain in this pond. These observations suggest that Pond 2 provided the most favorable conditions for the growth of Catla and Rohu, as evidenced by their larger final sizes, higher SGRs, and greater ADGs in this pond. On the other hand, Pond 3 appeared to be less conducive for the growth of these two species, as reflected by their smaller final sizes, lower SGRs, and lower ADGs compared to the other treatments.

The total fish biomass varied among the three ponds. Pond 2 had the highest biomass of 122.7 kg, followed by Pond 1 with 167.2 kg, and Pond 3 with 69.9 kg. The per hectare productivity ranged from 998.7 kg/ha to 1227.5 kg/ha, with Pond 2 being the most productive. In comparison to this study, Debnath et al. [12] reported fish productivity ranging from 934-1545 kg/ha in another hill state in NE India, Tripura, with a stocking density of 5000 fingerlings/ha. Das et al. [13] reported a productivity of 2,550 kg/ha in two-species fish culture in Meghalaya following a stocking density of 10000 fingerlings/ha.

The superior production in Pond 2 can be attributed to factors such as larger final sizes of fish, higher SGRs, and greater ADGs. In contrast, the lower production in Pond 3 may be due to intense inter-specific competition, especially between Common carp and Gonia. In Pond 1, the lag in fish biomass production compared to Pond 2 could be because of the aggressive feeding behavior of Common carp, which might lead to suboptimal resource utilization within the pond, thereby reducing overall fish productivity [17]. The fish’s dietary overlapping index might be significant (>6.0) in Pond 3, however, we could not assess the same in this study. A more comprehensive investigation is recommended to evaluate the dietary overlapping index between the fish species, which could provide further insights into the underlying causes of these productivity differences.

For Gonia and Common Carp, Pond 1 and Pond 2, respectively, were more favorable than pond 3. Gonia exhibited better growth performance in Pond 1, with a larger final size, higher SGR, and greater ADG compared to Pond 3. Similarly, Common Carp showed superior growth in Pond 2, with increased size at harvesting, SGR, and ADG relative to Pond 3. Since both the fish lives at the bottom, their feeding niches and spatial distribution likely overlapped significantly in pond 3 and when two species share a similar ecological niche and compete for the same resources, it can result in negative interactions, such as competition for food, territory, or other essential requirements [18]. This inter-specific competition can limit the ability of both species to obtain sufficient nutrients and optimal growing conditions, ultimately affecting their growth rates and overall performance as seen in this study in Pond 3. In contrast, Catla, which primarily occupies the surface of water column, and Rohu, which inhabits the middle of water column, have distinct feeding niches and spatial distributions. This separation of feeding zones and resource utilization could have reduced the potential for direct competition between these species in Pond 3. The lack of overlap in feeding niches between Catla, Rohu, and the bottom-dwelling species (Gonia and Common Carp) might have allowed for more efficient resource partitioning and minimized negative interactions. As a result, the growth performance of Catla and Rohu in Pond 3 might not have been impacted to the same extent as Gonia and Common Carp.

Overall, the study provided valuable insights over the importance of considering the ecological niches, feeding habits, and potential interactions between species when designing polyculture systems, as these factors can significantly impact the overall growth performance and productivity of the cultured species.

Meghalaya presents vast opportunities for hill aquaculture [19]. However, when it comes to prioritizing fish species in these hill regions, a cautious approach is necessary. Currently, there are no prioritized fish species specifically for Meghalaya climatic. In this scenario, this study focused on fish species that meet certain key criteria: locally available seed sources, good market demand, and tolerance to colder climatic conditions. While Catla and Rohu, two of the most widely cultivated Indian major carps, may not thrive optimally in the hill climate, their inclusion in the study was considered due to the readily available seed supply and local consumer preferences. The common carp, an introduced species, was chosen for its ability to tolerate hill climates, readily available seeds, and its important role as a detritus feeder in the aquatic ecosystem. Furthermore, Gonia, known locally as Khaski, was choosen due to its endemic nature, readily available seeds, and its ability to withstand the hill climates similar to that of Meghalaya. By integrating these selected fish, the aim was to explore the potential benefits of a composite culture system tailored specifically for hill ponds.

**Table 3. Fish growth parameters under different species compositions**

| Pond | Fish variety | Size | | SGR (%/day) | ADG (g/day) | Survival (%) | Fish biomass (kg/pond) | FCR | Condition factor (b) |
|---|---|---|---|---|---|---|---|---|---|
| | | At stocking (g) | At harvesting (g) | | | | | | |
| 1 | Catla | 28.4±1.8 | 357.6±30.9 | 1.05±0.01 | 1.37±0.12 | 81.1±7.8 | 167.2 ≈ | 1.60 | 2.1 |
| | Rohu | 7.5±0.4 | 282.0±32.2 | 1.50±0.02 | 1.14±0.13 | | 1114.8 | | 2.4 |
| | Gonia | 7.6±0.5 | 185.0±9.9 | 1.33±0.04 | 0.74±0.04 | | kg/ha | | 2.6 |
| 2 | Catla | 28.4±1.8 | 380.4±17.9 | 1.08±0.04 | 1.46±0.08 | 83.2±4.9 | 122.7 ≈ | 1.53 | 2.3 |
| | Rohu | 7.5±0.4 | 283.7±8.5 | 1.52±0.03 | 1.15±0.03 | | 1227.5 | | 2.6 |
| | Common carp | 10.8±1.3 | 221.1±10.1 | 1.25±0.04 | 0.87±0.03 | | kg/ha | | 2.5 |
| 3 | Catla | 28.4±1.8 | 360.8±21.7 | 1.05±0.03 | 1.38±0.08 | 82.3±4.9 | 69.9≈ | 1.64 | 2.0 |
| | Rohu | 7.5±0.4 | 264.3±15.1 | 1.48±0.01 | 1.06±0.06 | | 998.7kg/ha | | 2.3 |
| | Gonia | 7.6±0.5 | 157.6±16.4 | 1.26±0.02 | 0.62±0.06 | | | | 2.1 |
| | Common carp | 10.8±1.3 | 187.5±12.3 | 1.19±0.02 | 0.74±0.04 | | | | 2.2 |

### 3.4 Survival, Feed Conversion, and Condition Factor

The survival rate is a critical metric for evaluating the success of an aquaculture system. In this study, the survival rates were calculated for all fish species combined, providing an overall picture of survival across different ponds. In Pond 1, the survival was 81.1%, in Pond 2 it was 83.2%, and in Pond 3 it was 82.3%. Overall survival above 80% in all ponds could be considered a positive sign of successful fish health management and possible use of hill ponds for commercial aquaculture [20]. It also suggests that the fish were well-adapted to their environment and that the ponds provided favorable conditions for their growth.

The FCR is a critical parameter in aquaculture as it reflects the efficiency of feed utilization by the cultured fish species. A lower FCR value indicates better feed conversion efficiency. It is crucial to consider the FCR in conjunction with other parameters, such as fish biomass yield, growth rates, and survival rates, to evaluate the overall performance and productivity of the culture system [21]. n some cases, a slightly higher FCR might be acceptable if it is accompanied by higher fish biomass production or other desirable outcomes. In this study, the FCR was 1.60 in Pond 1, 1.53 in Pond 2, and 1.64 in Pond 3. These values were lower when compared with the findings in fish culture in Tripura by Debnath et al. [22]. These lower FCRs indicate that the used feeds were efficient; fishes were able to convert the feed into body mass more efficiently despite interspecific competitions or cold climate. The FCR values also align with the expected relationship between FCR and fish biomass, where the highest biomass production corresponded to the lowest FCR. It is important to note that a lower FCR not only indicates more efficient feed utilization but also has economic implications, as it can lead to reduced feed costs and potentially higher profitability for the aquaculture operation. Further study is recommended on the economic aspects of fish culture in hill ponds.

The condition factor (b) is a crucial indicator of fish's general well-being [7]. A b value of 3 indicates isometric growth, where weight increases proportionally with length [23,24,25]. Conversely, b values greater than 3 indicate positive allometric growth, signifying accelerated weight gain compared to length increase, which is particularly beneficial for biomass production. On the other hand, b values less than 3 indicate negative allometric growth, where fish become leaner rather than more robust or heavier, which is unfavorable for biomass production in fish culture. In this study, fish growth exhibited positive allometric growth across all ponds, indicating that the fish combinations followed are particularly advantageous for biomass production [23].

For Catla, Pond 2 displayed the highest b value, followed by Pond 1 and then Pond 3. This suggests that Catla in Treatment 2 experienced the most favorable growth conditions, while its growth in Treatment 3 was comparatively less efficient, possibly due to high interspecific competitions. Regarding Rohu, Pond 2 showcased the highest b value, followed by Pond 3 and then Pond 1. This indicates that Rohu in Pond 2 had the most efficient growth. Gonia exhibited the highest b value in Pond 1, followed by Pond 3. This suggests that Gonia experienced more favorable growth conditions in Treatment 1 compared to Treatment 3, which might be due to less interspecific competition. Similarly, Common Carp displayed a relatively high b value in Pond 2 and a lower value in Pond 3, which might be due to less interspecific competition with cohabiting fish. Overall, the b values reflect the complex interactions between different fish species, highlighting the need for careful management and understanding of these interactions to optimize growth and productivity.

### 3.5 Low-input Management and Sustainability

This study emphasized low-input management, aiming to develop a fish production system that small-scale farmers in hilly regions like Meghalaya, who face constraints in resources and purchasing power, can easily afford and adopt with minimal investment. This approach involved stocking fish seeds at a lower density of 5000 numbers/ha, in contrast to the general recommendation of 10,000 numbers/ha. By reducing stocking density, this method alleviated crowding stress on the fish and lowered their demand for supplementary feed. Furthermore, the feeding rate was maintained at 2%, as opposed to the typically recommended 4-5% in grow-out fish culture systems. This lower feeding rate, coupled with the utilization of locally available ingredients such as rice bran and mustard oil cake as fish feeds, substantially decreased operational costs and enhanced affordability for hill farmers. Additionally, the study skipped a tight fertilization schedule in the ponds, opting for a need-based pond fertilization approach where semi-dried cattle manure was applied only when the plankton density plummeted below 0.5 ml/50 liters of water. This approach not only reduces input costs but also minimizes issues like eutrophication or the formation of harmful algal blooms (HABs) in water, which are common issues in naturally stabilized earthen ponds.

While the fish productivity obtained in this study was low (998.7 kg/ha to 1227.5 kg/ha), the low-input management approach demonstrated a sustainable and locally adaptable system for hilly regions like Meghalaya. By utilizing naturally stabilized earthen hill ponds and incorporating locally available fish with dissimilar feeding habits, this study provided a practical solution for enhancing fish productivity in hill ponds and improving associated livelihood security, while minimizing environmental impacts and operational costs.

## 4. CONCLUSION

This study demonstrated the potential of utilizing naturally-stabilized earthen ponds for developing low-input aquaculture systems tailored to the hilly regions of Meghalaya. By evaluating different fish species compositions, including surface-feeders, column-feeders, and bottom-dwellers, valuable insights were gained into the productivity and sustainability of these ponds. The nutrient-rich sediments, sustained plankton production, and optimal water quality parameters supported fish growth and survival, with Pond 2 exhibiting the highest biomass yield of 1227.5 kg/ha. However, interspecific competition between bottom-dwelling species like Gonia and Common carp highlighted the need for careful selection of compatible species combinations. Overall, this research suggests that naturally-stabilized earthen ponds can serve as valuable resources for hill aquaculture, provided that fish species are judiciously chosen to minimize competition and maximize resource utilization. Further investigations into species interactions, nutrient dynamics, and economic viability are recommended to refine and optimize these sustainable aquaculture practices in hilly regions.

## ETHICAL APPROVAL

This study was conducted using the funds received under the institute's contingency fund. The ethical guidelines provided by the Institutional Ethics Committee, ICAR Research Complex for NEH Region, were followed throughout the course of this study.

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## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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