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Habitat Characteristics and Gonadal Maturity Assessment of Keudawah (*Rasbora arundinata* Lumbantobing, 2014) to Support Management and Domestication Strategies

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ABSTRACT

The Krueng Lanca River in Aceh Province is an ecologically important freshwater system that supports local livelihoods and aquatic biodiversity. *Rasbora arundinata*, a native rheophilic fish species, inhabits the river's fast-flowing upstream reaches, characterized by rocky-sandy substrates and dense riparian vegetation. This study investigates the species' reproductive biology and habitat preferences to support sustainable management and domestication efforts. Over a 12-month period, data on physicochemical parameters, habitat structure, gonadosomatic index (GSI), and fecundity were collected from six sampling stations. The species was found to prefer moderate to fast-flowing waters with coarse substrates and optimal environmental conditions: temperature (26.03–27.72 °C), pH (6.98–7.69), turbidity (1.62–3.73 NTU), and dissolved oxygen (5.41–6.74 mg/L). Spawning activity peaked in April and September. Strong correlations were observed between environmental factors and reproductive indices, including turbidity and male GSI ($r = 0.71$), average catch and GSI ($r = 0.87$), TDS and female GSI ($r = 0.76$), and temperature and female GSI ($r = 0.41$). Station 2 was identified as the core spawning site due to its stable hydrological conditions and the highest GSI and catch rates. These findings provide critical ecological insights for habitat-based conservation strategies and the development of sustainable aquaculture systems for *R. arundinata* in tropical river ecosystems.

INTRODUCTION

Krueng Lanca, located in Nagan Raya Regency, Aceh Province, Sumatra (Indonesia), forms part of the tropical Indo-Malayan freshwater ecoregion, one of the world's biodiversity hotspots. Recognized as one of three key inland rivers in Aceh's public waters **(Muchlisin, 2012)**, Krueng Lanca is a crucial water source, transportation corridor, and livelihood base for surrounding communities. Among its ichthyofauna is

Rasbora arundinata, a rheophilic fish species endemic to upstream (ritron) habitats characterized by swift currents and heterogeneous substrates.

R. arundinata prefers habitats with strong flow regimes, rocky and sandy substrates, and high dissolved oxygen levels. The dense riparian vegetation along the riverbanks functions as a natural barrier against sedimentation while supplying essential organic matter crucial for the functioning of the aquatic ecosystem **(Kumwimba *et al.*, 2024)**. This species also relies on inputs from riparian flora and aquatic fauna, which provide vital nutrition, refuge from predators, and contribute to its reproductive success **(Šmejkal *et al.*, 2023)**. However, the habitat of *R. arundinata* in Krueng Lanca is increasingly threatened by anthropogenic pressures such as land conversion, deforestation, and mining activities. According to **Abdan *et al.* (2024)**, land-use changes, compounded by unsustainable fishing practices, have further deteriorated the quality of its habitat. Additionally, pesticide runoff from agricultural practices contributes to water pollution, adversely affecting aquatic biodiversity and disrupting fish life cycles **(Damor, 2024)**.

Previous studies on *Rasbora* species have mainly explored general habitat preferences, emphasizing the role of sandy and rocky substrates as shelter and feeding grounds **(Mohd-Azham & Singh, 2019)**. Recent surveys indicate that several *Rasbora* species inhabit moderate to high flow waters, often adjacent to agricultural zones, rendering them vulnerable to sedimentation and chemical pollutants stemming from upstream land-use changes **(Muhtadi *et al.*, 2023)**. Nonetheless, detailed ecological and reproductive studies specific to *R. arundinata* remain scarce, particularly regarding its spawning habitat requirements and gonadal development under natural conditions.

Bridging this knowledge gap is essential for developing targeted conservation and management strategies. This study examines the habitat characteristics and spawning sites of *R. arundinata* in Krueng Lanca based on gonadal maturity stages. Integrating data on physical-chemical water parameters, substrate composition, and riparian vegetation with reproductive biology, this research seeks to provide a comprehensive understanding of the factors influencing *R. arundinata* reproduction and habitat utilization. The findings would support sustainable fisheries management and ecologically sound aquaculture development, thereby contributing to the long-term viability of *R. arundinata* populations and freshwater biodiversity conservation in tropical river ecosystems.

MATERIALS AND METHODS

Study site

This study was conducted in the Krueng Lanca River, located in Nagan Raya Regency, Aceh Province, over 12 months, from 17 January to 19 December 2023. Six sampling stations were selectively chosen to represent the diverse habitat characteristics of *Rasbora arundinata* (Fig. 1 & Table 1). The selection of these stations aimed to provide a comprehensive representation of the river's ecological gradient, encompassing variations in flow regimes, substrate composition, and riparian vegetation.

Data collection

This study utilized both primary and secondary data sources. Primary data comprised the aquatic environment's physical, chemical, and biological parameters. The physical parameters included river depth, width, current velocity, water temperature, transparency, and turbidity. Chemical parameters consisted of dissolved oxygen (DO), pH, total dissolved solids (TDS), and electrical conductivity. Biological parameters focused on the gonadal development of *Rasbora arundinata*.

Measurements were conducted through a combination of visual observations, manual techniques, and digital sensor-based instruments. Meso-habitat characteristics, river slope, and substrate composition were recorded through direct field observations. River depth was measured using a graduated measuring rod, and river width was measured using a measuring tape. Current velocity was recorded with a digital current meter (Flowatch FL-02). Water transparency was measured using a standard Secchi disk. In situ water temperature and DO measurements were taken using a portable DO meter (DO9100). TDS and conductivity were measured with a digital TDS/EC meter (TP AH-05), turbidity with a Lutron turbidity meter, and pH with a digital pH meter (TP-AH05).

Fish specimens were collected using gill nets with mesh sizes of 0.5 and 1.0 inches, and cast nets with a diameter of 6 meters and a mesh size of 0.5 inches. Captured specimens were preserved in 10% formalin, labeled, and stored in plastic sampling bags. Each label contained information on sampling location, date, gear type, collector's name, and the number of individuals collected. On average, monthly catches comprised 50–54 male and 59–63 female individuals. Secondary data included historical water quality and land use records, obtained from relevant governmental reports and publications.

To ensure data reliability, all environmental parameters were measured in triplicate at each sampling station. Instruments were calibrated before and after each field session. Mean values were used in subsequent statistical analyses to minimize measurement error.

The gonadosomatic index (GSI) was calculated following the method described by **Effendi (1979**), using the formula:

$$GSI\ (\%) = (\text{Gonad weight} / \text{Total body weight}) \times 100$$

Data Analysis

Data analysis was performed using the analysis of variance (ANOVA) and Tukey's post-hoc test to evaluate differences in physicochemical characteristics among variables **(Kaufmann & Schering 2014)**. The principal component analysis (PCA) was employed to identify relationships between environmental parameters and habitat suitability, while cluster analysis was used to group sampling stations based on similarities in measured parameters **(Tusubira *et al.* 2001)**. In addition, a correlation matrix analysis was conducted to assess the relationships between environmental parameters and fish reproductive performance **(Zhang *et al.* 2015)**. The results were visualized using heatmaps to identify significant associations with the gonadosomatic Index (GSI). All statistical analyses were carried out using Minitab software version 21.

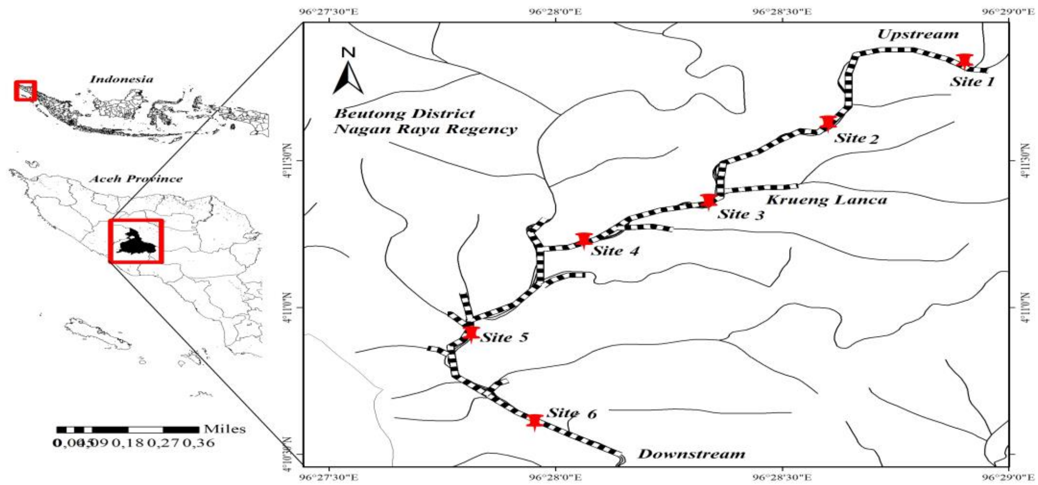

Fig. 1. Sampling locations in the Krueng Lanca River, Aceh Province, Indonesia

Table 1. Description of the sampling locations in the Krueng Lanca River

No	Station	General description of the location	Coordinates
1	I	The water condition is medium flowing with the shade of plant vegetation along the river, sandy mud water bottom, and there is a lot of plant litter and water holes with a depth of >100cm, river width 10-15 meters	96°28'54,122"E 4°11'49,213"N
2	II	The water condition is medium flowing with sandy, muddy water bottom, gravel, hollows in this location, and the shade of plant vegetation along the river. The width of the river is ± 10-15 meters, and the depth is > 80-100cm.	96°28'35,538"E 4°11'37,564"N
3	III and IV	Water conditions are moderate with sandy and rocky bottom waters. The location has community gold mining activities with a depth of <50cm, river width ±10-15 meters. Along the location, there are community oil palm plantation activities.	96°28'12,517"E 4°11'13,433"N dan 96°28'20,283"E 4°11'21,476"N
4	V	Medium flow location with sandy bottom and depth <50-100 cm, river width ±15-20 meters.	96°27'48,109"E 4°10'53,74"N
5	VI	. Current location with rocky water bottom and depth <50cm, river width ±15 meters	96°27'56,985"E 4°10'35,988"N

RESULTS

Physicochemical characteristics of the Krueng Lanca River

Between January and December 2023, a total of 1,375 individuals of *Rasbora arundinata* were collected from six sampling stations along the Krueng Lanca River, comprising 637 males and 738 females. These specimens were used to examine the relationship between environmental parameters and reproductive performance through the gonadosomatic index (GSI). Spatially, the river exhibited relatively stable physicochemical conditions, with low variability across stations. Water temperature ranged from 26.50 ± 0.73°C at Station V to 26.96 ± 0.71°C at Station I. Turbidity varied from 2.00 ± 0.24 NTU (Station VI) to 3.00 ± 0.77 NTU (Station IV), while current velocity ranged from 0.45 ± 0.08 m/s to 0.60 ± 0.10 m/s, with the highest velocity observed at Station V.

Chemical parameters also showed moderate spatial variation. Electrical conductivity (EC) ranged from 42.17 ± 5.46 µS/cm at Station VI to 46.49 ± 5.06 µS/cm at Station V. pH values ranged between 7.25 ± 0.22 (Station I) and 7.69 ± 0.22 (Station II), while dissolved oxygen (DO) concentrations ranged from 5.90 ± 0.36 to 6.19 ± 0.40 mg/L. Water depth varied between 0.40 ± 0.06 m (Station I) and 0.60 ± 0.10 m (Station V), and total dissolved solids (TDS) ranged from 24.27 ± 1.12 mg/L (Station VI) to 28.75 ± 1.12 mg/L (Station I). Tukey's post hoc test revealed statistically significant differences in water depth and TDS across stations, whereas other parameters such as temperature, turbidity, current velocity, conductivity, pH, DO, and average catch did not differ significantly ($P > 0.05$). The average number of fish caught per station ranged from 23.25 ± 4.96 individuals (Station VI) to 33.25 ± 6.57 individuals (Station V) (Table 2).

Temporally (Table 3), the Krueng Lanca River showed apparent seasonal variation in physicochemical conditions and biological responses throughout 2023. Water temperature ranged from 26.03 ± 0.43°C in June to 27.72 ± 0.52°C in May, with higher values during the early dry season and lower ones during wetter months. Turbidity fluctuated between 1.62 ± 0.67 and 3.73 ± 0.79 NTU, peaking in July due to surface runoff and declining in September. Depth remained shallow overall, varying from 0.37 ± 0.08 m in January to 0.53 ± 0.04 m in June and December, reflecting rainfall influence. Current velocity increased steadily from 0.31 ± 0.04 m/s to 0.63 ± 0.07 m/s by year-end, indicating seasonal discharge buildup.

TDS and conductivity followed similar trends, increasing from 38.23 ± 5.23 mg/L and 39.83 ± 1.67 µS/cm in early months to 50.40 ± 9.82 mg/L and 47.33 ± 8.08 µS/cm in December. These increases were likely driven by cumulative solute input during wetter periods. pH remained neutral, ranging from 6.98 ± 0.12 (March) to 7.79 ± 0.12 (June), while DO varied from 5.41 ± 0.10 mg/L in January to 6.74 ± 0.22 mg/L in August, suggesting improved oxygenation during drier, high-flow periods. Rainfall peaked in January (399.1mm) and was the lowest in June (114.4mm), shaping trends in depth, turbidity, velocity, and DO.

Table 2. Average physical-chemical parameters of spatial waters in Krueng Lanca

Parameters	Station						
	I	**II**	**III**	**IV**	**V**	**VI**	**Referensi**
Temperature (°C)	26.96±0.71[a]	26.78±0.48[a]	26.81±0.90[a]	26.78±0.48[a]	26.50±0.73[a]	26.79±0.49[a]	24-28 (Muhtadi 2023)
Turbidity (NTU)	2.41±0.98[a]	2.62±0.98[a]	2.79±0.98[a]	3.00±0.77[a]	2.59±0.41[a]	2.20±0.24[a]	-
Depth (m)	0.40±0.06[c]	0.42±0.05[c]	0.54±0.09[ab]	0.43±0.05[c]	0.60±0.10[a]	0.49±0.06[b]	-
Current Speed (m/s)	0.45±0.08[a]	0.45±0.08[a]	0.46±0.14[a]	0.46±0.08[a]	0.48±0.10[a]	0.48±0.08[a]	0,1-1,5 m/s (Muhtadi 2023)
Total dissolved suspension (TDS) (mg/L)	27.48±1.12[a]	26.38±1.12[ab]	26.06±1.12[b]	25.76±1.12[bc]	24.46±1.12[cd]	24.27±1.12[d]	20 – 90 mg/L (Muhtadi 2023)
Conductivity (µS/cm)	42.25±3.34[a]	44.36±3.31[a]	43.42±2.75[a]	45.92±7.05[a]	47.00±6.49[a]	42.17±5.46[a]	40-70 (Muhtadi 2023)
pH	7.45±0.22 [a]	7.69±0.22 [a]	7.33±0.22[a]	7.56±0.22[a]	7.58±0.22[a]	7.45±0.22[a]	6,5-8,0 (Muhtadi 2023
Dissolved oxygen (DO) (mg/L)	6.19±0.40[a]	5.93±0.40[a]	6.16±0.40[a]	6.04±0.40[a]	5.90±0.36[a]	6.17±0.40[a]	>3 mg/L (Muhtadi 2023
Average catch (Ind)	30.51±4.13[a]	33.25±6.57[a]	30.92±4.97[a]	30.75±5.29[a]	29.75±4.13[a]	29.42±4.31[a]	-
River width (m)	14	15	24	21	19	17	-
River slope (m)	Slightly sloped	Slightly sloped	Slightly sloped	Slightly sloped	Ramps	Ramps	-
Meso-habitat	Pool, riparian vegetation	Rifle/Pool, riparian vegetation	Riffle/Pool, plantations, and riparian vegetation	Pool, plantations	Rifle	Rifle	-
Subtrate	Gravelly and muddy	Rocky, slightly sandy, and muddy	Rocky, slightly sandy, and muddy	Sandy rocky	Sandy rocky	Rocky	-
Male GSI (%)	7.82±3.94	9.01±3.16	8.69±2.94	8.54±2.96	7.65±3.12	7.41±2.83	-
Female GSI (%)	11.38±2.87	11.93±3.72	11.17±4.04	10.54±3.25	10.57±3.80	10.33±4.42	-

[1] Values followed by the same superscript letter (a–d) within the same row are not significantly different at the 5% significance level (Tukey's post hoc test)

Table 3. Average physico-chemical parameters of the temporal waters in Krueng Lanca

Parameters	Month											
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Temperature (°C)	26.31±0.5^{cd}	26.72±0.5^{bcd}	27.12±0.5^{abc}	27.32±0.5^{ab}	27.72±0.5^{a}	26.03±0.3^{d}	26.20±0.2^{cd}	26.43±0.6^{bcd}	26.87±0.6^{abcd}	27.35±0.1^{ab}	26.80±0.0^{abcd}	26.35±0.1^{cd}
Turbidity (NTU)	1.82±0.1^{ef}	2.03±0.2^{cdef}	2.25±0.2^{cdef}	1.62±0.7^{f}	1.91±0.7^{def}	2.85±0.2^{abcd}	3.04±0.3^{abc}	2.83±0.2^{abcde}	2.30±0.3^{bcdef}	3.31±0.6^{ab}	3.52±0.7^{a}	3.73±0.8^{a}
Depth (m)	0.37±0.1^{a}	0.46±0.1^{a}	0.47±0.1^{a}	0.52±0.1^{a}	0.52±0.1^{a}	0.53±0.1^{a}	0.52±0.1^{a}	0.51±0.1^{a}	0.48±0.1^{a}	0.49±0.2^{a}	0.47±0.1^{a}	0.51±0.1^{a}
Current speed (m/s)	0.31±0.1^{f}	0.40±0.1^{cdef}	0.37±0.1^{ef}	0.38±0.1^{def}	0.41±0.1^{cde}	0.46±0.1^{bcd}	0.49±0.1^{bc}	0.51±0.1^{b}	0.51±0.1^{b}	0.52±0.1^{b}	0.61±0.1^{a}	0.63±0.1^{a}
Total dissolved solids (TDS) (mg/L)	42.33±8.2^{a}	46.55±9.0^{a}	46.93±9.1^{a}	38.23±5.3^{ab}	47.70±9.3^{a}	48.09±9.4^{a}	48.47±9.4^{a}	48.86±9.5^{a}	49.24±9.6^{a}	49.63±9.7^{a}	50.01±9.7^{a}	50.40±9.8^{a}
Conductivity (µs/cm)	43.17±4.9^{ab}	45.02±2.1^{ab}	41.33±2.6^{ab}	39.83±1.7^{ab}	45.67±3.9^{ab}	49.02±3.4^{a}	39.17±4.2^{b}	44.17±5.1^{ab}	45.50±4.9^{ab}	46.68±5.9^{ab}	43.33±3.4^{ab}	47.33±8.1^{a} ^{b}
pH	7.39±0.1^{ef}	7.27±0.1^{fg}	7.38±0.1^{g}	7.69±0.1^{abc}	7.44±0.1^{def}	7.79±0.1^{a}	7.54±0.1^{bcde}	7.46±0.1^{cdef}	7.61±0.1^{abcd}	7.57±0.1^{abcde}	7.24±0.1^{ab}	6.67±0.1^{abcd}
Dissolved oxygen (DO) (mg/L)	5.41±0.1^{j}	5.61±0.1^{ij}	5.81±0.1^{ghi}	6.01±0.1^{efg}	6.21±0.1^{cde}	6.41±0.1^{bc}	6.61±0.1^{ab}	6.74±0.2^{a}	5.69±0.1^{hi}	5.89±0.1^{fgh}	6.09±0.1^{def}	6.29±0.1^{cd}
Average catch (Ind)	33.00±2.4^{abcd}	20.67±2.8^{e}	27.83±3.3^{d}	38.33±4.6^{a}	31.33±1.6^{bcd}	29.67±1.9^{cd}	29.67±1.7^{cd}	30.83±5.0^{ab}	35.50±1.1^{bcd}	34.00±1.9^{abc}	29.50±1.7^{cd}	32.83±2.6^{a} ^{bcd}
Rainfall (mm)	221.4	151.2	378	181.5	246.1	420.4	243.8	408.1	374.5	391	336.1	392.1
Male GSI	6.96±2.6	7.86±2.0	7.78±2.8	9.10±3.5	8.041±2.8	7.556±3.6	8.31±3.2	8.53±3.2	8.98±3.5	8.37±3.4	7.98±3.2	8.30±3.7
Female GSI	10.148±5.9	10.871±2.8	12.042±4.02	12.619±4.2	11.209±3.8	10.618±3.70	10.425±3.76	11.133±2.87	11.691±3.78	10.168±4.13	10.578±3.94	10.835±3.11
Fecundity	1137±644.0	318±50.39	1956±876.7	2150±1016.9	2141±1692.6	1801±899.9	1685±484.5	1494±625.1	1901±724.3	2090±749.1	1822±636.8	1775±644.61

[1] Values followed by the same superscript letter (a–j) within the same row are not significantly different at the 5% significance level (Tukey's post hoc test)

Relationship between environmental parameters and gonadosomatic index

Principal component analysis (Fig. 2a) revealed that Station II displayed distinct environmental characteristics compared to other stations. This station was characterized by specific substrate composition, river slope, meso habitat, and higher levels of dissolved oxygen—factors that collectively support optimal gonadal development in both male and female individuals, as reflected in elevated GSI values. Moreover, this station recorded a higher average catch, emphasizing its ecological significance as a potential spawning and feeding habitat for *Rasbora arundinata*.

Cluster analysis using the complete linkage method and Euclidean distance (Fig. 2b) grouped the six sampling stations into two primary clusters based on environmental similarity. Cluster 1 comprised stations VI and V, which were characterized by greater water depth and more stable conductivity. Cluster 2 included stations I, II, III, and IV, which exhibited higher variability in environmental conditions among stations.

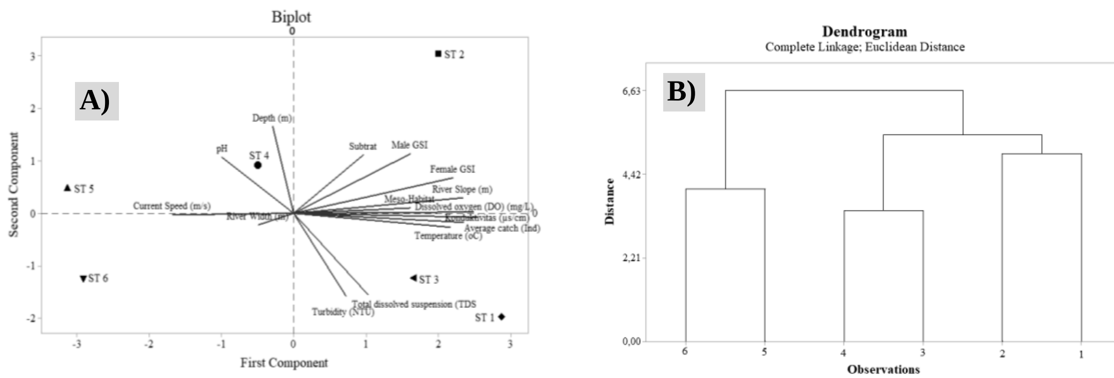

Fig. 2 a) Biplot of Principal Component Analysis (PCA) of physico-chemical parameters and b) Dendrogram of station clustering of Krueng Laca.

Correlation matrix between environmental parameters and GSI

The correlation matrix (Fig. 3) revealed complex relationships between environmental parameters and the gonadosomatic index (GSI) of *Rasbora arundinata*. Temperature showed a significant positive correlation with total dissolved solids (TDS) (0.74) and dissolved oxygen (DO) (0.76). Turbidity had a strong positive correlation with male GSI (0.71) and a moderate correlation with average catch (0.35). Water depth was positively correlated with current velocity (0.75), but negatively correlated with average catch (-0.48). DO exhibited a strong negative correlation with conductivity (-0.84), and a positive correlation with temperature (0.76). Both male and female GSI showed a strong positive correlation with average catch (0.87).

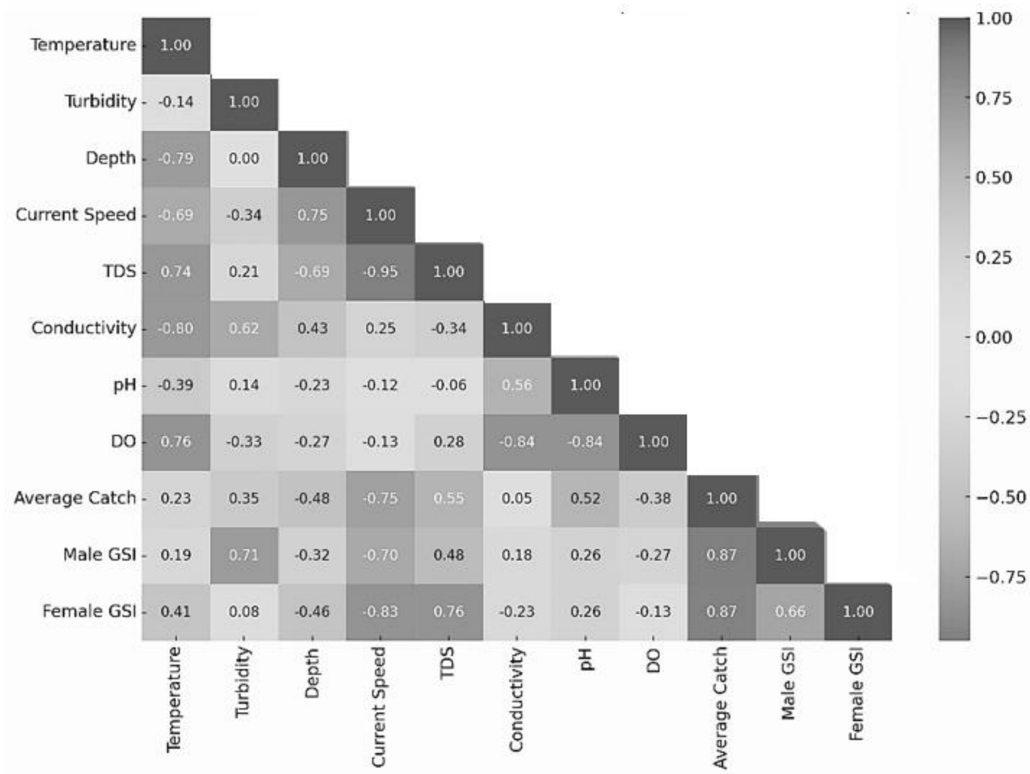

Fig. 3 Correlation matrix between environmental parameters and gonadosomatic index (GSI) in Krueng Lanca

DISCUSSION

Physicochemical parameters and reproductive habitat

The spatial stability of physicochemical parameters along the Krueng Lanca River indicates that the aquatic environment is generally suitable for the reproductive activities of *Rasbora arundinata*. Key parameters such as water temperature (26–28 °C), dissolved oxygen (5.90–6.74 mg/L), and neutral to slightly alkaline pH (7.25–7.69) support reproductive physiology and endocrine activity in tropical freshwater fish **(Brahman & Chandra, 2014; Mridul *et al*., 2024)**. Water temperature was positively correlated with both DO (r = 0.76) and total dissolved solids (TDS) (r = 0.74), confirming that optimal thermal conditions enhance metabolic activity and oxygen uptake during gonadal development **(Abedin *et al*., 2024; Lema *et al*., 2024; Santhakumar, 2024)**. Conversely, temperature was negatively correlated with conductivity (r = -0.80) and water depth (r = -0.79), suggesting that reproductive activity is favored in warmer, shallower areas with moderate current, which promote substrate stability and minimize larval drift **(Keckeis, 2001).**

The ionic composition reflected in TDS also plays a significant role in oocyte maturation. Dissolved ions such as calcium, magnesium, phosphate, and bicarbonate contribute directly to vitellogenesis and yolk protein synthesis. Calcium and magnesium aid in oocyte wall formation and vitellin deposition **(Lee & Hu, 1983; Reading *et al*.,**

2017), while phosphate supports ATP synthesis and vitellogenin production **(Amutha *et al*., 2023; Ferdinand *et al*., 2023; Silvester *et al*., 2023)**. When TDS levels are within the optimal range, physiological processes proceed efficiently without osmotic stress **(Ballester-Lozano *et al*., 2015; Chapman & McPherson, 2016)**. Seasonal fluctuations in rainfall also influenced environmental parameters temporally. As observed, DO concentrations peaked during the dry and post-rainfall periods, indicating enhanced oxygenation from increased flow and flushing events. These environmental windows trigger reproductive readiness in *R. arundinata*, linking habitat quality directly to climatic seasonality **(Kang *et al*., 2015)**.

Habitat classification and gonadosomatic index association

Microhabitat structure—including substrate type, slope, and riparian vegetation—strongly influenced reproductive success. Rocky and sandy substrates combined with moderate current velocity and depth created stable conditions for egg deposition and reduced physical disturbances to developing larvae **(Nagel *et al*., 2020; Lehtonen & Veneranta, 2024)**. Riparian vegetation, in particular, provided shading, moderated water temperature, and reduced sedimentation, thus contributing to a favorable mesohabitat for spawning and larval survival **(Oester *et al*., 2024)**.

PCA results revealed that specific sampling sites, notably Station 2, were environmentally distinct and strongly associated with higher GSI values for both sexes. This association suggests that habitat classification based on physical and chemical attributes predicts reproductive site suitability. The strong positive correlation between female and male GSI ($r = 0.87$) further supports the presence of synchronized reproductive cycles in habitats with optimal environmental conditions. Similar patterns have been observed in *Oreochromis niloticus*, where GSI values differed significantly across canal habitats with distinct environmental profiles, confirming the utility of GSI as a reliable indicator of habitat-driven reproductive potential **(Khallaf *et al*., 2018)**.

This synchronicity reflects a biological strategy common in cyprinids, where external fertilization requires temporal alignment in gamete release **(Takemura *et al*., 2010; Kaharuddin *et al*., 2024)**. The environmental cues synchronizing gamete development, particularly temperature, DO, and substrate quality, are critical in determining reproductive habitat suitability.

Correlation between environmental parameters and GSI

The correlation matrix revealed intricate relationships between environmental variables and the gonadosomatic index (GSI) of *Rasbora arundinata*. Temperature, TDS, and DO had strong positive correlations with both male and female GSI, while turbidity was significantly associated with male GSI ($r = 0.71$), potentially due to its role in reducing visual predation and supporting territorial behavior in males **(Sularto *et al*., 2023; Al Sawaf *et al*., 2024)**. Moderate water depth also positively correlated with male GSI ($r = 0.48$), providing thermal stability and reducing physical threats to larvae **(Goodman *et al*., 2018; Yoshida *et al*., 2024)**. The observed positive correlation between

DO and GSI underscores the oxygen-dependent nature of reproductive physiology, particularly during the final stages of gonadal maturation.

The most critical finding is the strong correlation between GSI and average catch (r = 0.87), indicating that favorable reproductive conditions influence fish abundance. This suggests that environmental suitability supports gonadal development and enhances population-level responses by concentrating mature individuals in high-quality habitats **(Al Mahmud *et al*., 2016; Claisse *et al*., 2019)**.

Furthermore, seasonal trends in environmental data show alignment with biological responses. GSI peaks in April and September correspond with declining or stabilizing rainfall, improved DO, and reduced turbidity conditions known to facilitate external fertilization and embryo development. The responsiveness of *R. arundinata* to seasonal hydrological shifts reflects an environmentally cued reproductive strategy that parallels observations on *R. lateristriata*, *R. tawarensis* and *D. rerio* **(Muchlisin *et al*., 2010; Sentosa & Djumanto, 2010; Massey *et al*., 2022)**. This pattern is further supported by findings for *Metapenaeus affinis*, where seasonal variations in GSI were strongly associated with environmental changes, highlighting the influence of climatic cycles on reproductive readiness **(Jabbar *et al*., 2025)**.

Spawning habitat of *Rasbora arundinata*

Among the six sampling stations, Station 2 emerged as the core spawning habitat based on integrating physical, chemical, and biological indicators. This site featured ideal conditions: rocky-sandy substrates, moderate flow, vegetative cover, high DO, and optimal TDS levels. These factors created a stable reproductive niche where environmental triggers aligned with gonadal readiness. The synchrony between peak GSI, high fecundity, and moderate turbidity at Station 2 supports the conclusion that this location offers ecological protection and physiological stimulation for spawning. In contrast, stations affected by anthropogenic activities (e.g., mining and land conversion) showed elevated turbidity, degraded substrates, and lower GSI values, indicating reproductive suppression due to habitat disturbance **(Kelly *et al*., 2020; Chojnacki *et al*., 2023; Damseth *et al*., 2024)**.

Station 1, characterized by muddy substrates and decomposing leaf litter, exhibited conditions that make egg and larval survival at risk due to unstable sediment and reduced oxygen diffusion. These degraded conditions further emphasize the ecological importance of maintaining high-quality spawning habitats. Based on the current findings, Station 2 should be designated as a core conservation zone. Its ecological attributes serve as a reference model for habitat protection and species domestication initiatives. Management strategies should include seasonal fishing restrictions (April and September), visual demarcation of conservation boundaries, establishment of community-based monitoring groups (pokmaswas), and riparian reforestation. These reproductive peaks align with those recorded in the study of **Abdan *et al.* (2025)** reinforcing the temporal consistency of spawning events for *R. arundinata* in the Krueng Lanca River.

Furthermore, Station 2's suitability as a broodstock source highlights its vital role in long-term conservation and restocking programs **(Tripathi *et al*., 2024)**.

Management implications for sustainable reproductive habitat

The findings of this study provide a scientific basis for developing habitat-based management strategies to sustain *Rasbora arundinata* populations in the Krueng Lanca River. Identifying Station 2 as a core reproductive habitat highlights the need for spatially targeted conservation actions. Protecting this habitat through formal designation as a seasonal conservation zone, particularly during the reproductive peaks in April and September, can help reduce anthropogenic pressure during critical reproductive periods. Riparian buffer restoration should be prioritized to stabilize riverbanks, reduce sediment input, and support ecological resilience to ensure long-term habitat quality. Establishing community-based monitoring units can enhance enforcement and community engagement, ensuring local stewardship in protecting spawning habitats.

Additionally, the ecological parameters observed at Station 2—such as substrate type, current velocity, temperature, DO, and TDS can serve as a template for broodstock conditioning and aquaculture system design. Replicating these conditions in hatchery environments may improve reproductive performance, fertilization success, and larval viability. This integration of habitat conservation with aquaculture development aligns with ecosystem-based management approaches and supports both *in situ* and *ex-situ* strategies for sustainable fisheries management. In the broader context, these recommendations emphasize the importance of maintaining hydrological integrity and environmental seasonality, which are fundamental to sustaining natural reproductive cycles. Adaptive management—guided by continuous monitoring of environmental parameters and reproductive indicators—is essential to anticipate ecological changes and ensure long-term viability of *R. arundinata* populations.

CONCLUSION

This study demonstrates that the reproductive success of *Rasbora arundinata* in the Krueng Lanca River is closely linked to habitat characteristics, including water temperature (26– 28°C), dissolved oxygen (5.9– 6.7mg/ L), TDS (26– 28mg/ L), rocky-sandy substrates, and dense riparian vegetation. Station 2 was identified as the core spawning habitat based on high gonadal maturity and catch rates. Integrating physicochemical parameters with reproductive indicators reveals that seasonal environmental shifts—particularly post-rainfall transitions—trigger synchronized spawning. These findings provide a strong scientific basis for habitat-based conservation, seasonal fishing regulations, and the design of ecologically informed aquaculture systems, supporting the long-term sustainability of *R. arundinata* and freshwater biodiversity in tropical river ecosystems.

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