



Fish Biodiversity as Ecological Support for False Gharial (*Tomistoma schlegelii*) Habitats in Tropical Rivers

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ABSTRACT

Purpose of the study: This study aimed to analyze fish biodiversity and evaluate physicochemical water conditions supporting fish communities and the habitat sustainability of the false gharial (*Tomistoma schlegelii*) in a tropical freshwater river ecosystem.

Methodology: This study used a purposive sampling method at three observation stations. Fish samples were collected using gill nets, fishing rods, traps, and traditional fishing gear. Water quality parameters were measured in situ using GPS, thermometer, pH meter, Secchi disk, stopwatch, and current-flow method, while dissolved oxygen and heavy metals were analyzed ex situ using Atomic Absorption Spectroscopy. Fish identification referred to Kottelat in 1993. Data were analyzed using Shannon–Wiener diversity index, evenness index, similarity index, dominance index, and Pearson correlation analysis with SPSS version 22.

Main Findings: A total of 15 fish species were identified within the freshwater ecosystem. Fish diversity at all stations was categorized as moderate, with high evenness, high similarity, and low dominance values indicating relatively stable ecological conditions. Water temperature ranged from 28–29°C, dissolved oxygen from 6.4–6.8 mg/L, and pH remained at 6. Water transparency showed the strongest positive correlation with fish biodiversity ($r^2 = 0.948$), followed by dissolved oxygen and current velocity. Heavy metal concentrations remained below environmental quality standards.

Novelty/Originality of this study: This study provides an integrated ecological assessment linking fish biodiversity, physicochemical water quality, and habitat suitability for the false gharial within a tropical freshwater ecosystem. This research highlights the ecological relationship between aquatic biodiversity and prey-resource availability supporting false gharial habitat sustainability.

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1. INTRODUCTION

Freshwater river ecosystems in tropical regions represent one of the most important habitats supporting global aquatic biodiversity [1], [2]. Tropical rivers provide ecological functions for fish communities, nutrient cycling, food-web interactions, and ecosystem stability. Fish diversity in freshwater ecosystems is strongly

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influenced by habitat complexity, water quality, hydrological conditions, and riparian vegetation [3], [4]. Changes in environmental conditions may alter fish community composition and reduce ecological resilience in riverine habitats [5], [6]. Therefore, studies on fish biodiversity and environmental characteristics are essential for understanding the ecological condition of tropical freshwater ecosystems.

Fish communities play an important ecological role in maintaining the trophic structure and energy flow within freshwater ecosystems. The diversity and abundance of fish species can reflect the quality and stability of aquatic habitats because fish are highly responsive to environmental changes [7], [8]. Several freshwater fish species also function as ecological indicators of habitat degradation, pollution, and hydrological disturbance [9], [10]. In tropical wetlands and peat swamp rivers, fish assemblages are closely associated with environmental parameters such as dissolved oxygen, pH, temperature, and vegetation cover [11], [12]. Consequently, the assessment of fish biodiversity combined with environmental variables is widely used in aquatic ecological and conservation studies.

The false gharial, *Tomistoma schlegelii*, is one of the freshwater crocodilian species distributed in Southeast Asia and categorized as a threatened species due to habitat degradation and human disturbance [13], [14]. This species commonly inhabits peat swamp forests, blackwater rivers, wetlands, and slow-flowing freshwater ecosystems with dense vegetation cover. The ecological sustainability of false gharial populations is strongly dependent on habitat quality and the availability of aquatic prey, particularly fish communities [15], [16]. Fish constitute the primary food resource for juvenile and adult false gharials, making ichthyofaunal diversity an important component of habitat suitability. Therefore, the ecological relationship between fish communities and false gharial habitats has become an important issue in freshwater conservation biology [17], [18].

Environmental conditions in river ecosystems directly influence the distribution and survival of both fish communities and aquatic reptiles. Parameters such as water temperature, dissolved oxygen, pH, turbidity, depth, and current velocity can affect fish diversity and habitat utilization patterns [19], [20]. Habitat degradation caused by land conversion, pollution, sedimentation, and anthropogenic activities may reduce the ecological integrity of river systems [21], [22]. These environmental disturbances may indirectly threaten false gharial populations through reductions in prey availability and habitat quality. Accordingly, studies integrating fish biodiversity and aquatic environmental conditions are necessary to support freshwater ecosystem management and species conservation [23], [24].

Previous studies related to *Tomistoma schlegelii* have generally focused on habitat characteristics, population distribution, and species ecology, while studies integrating fish biodiversity and aquatic environmental conditions remain limited. Saputro et al., [25] investigated the habitat characteristics of *Tomistoma schlegelii* in the Sekonyer River, Central Kalimantan, and emphasized the importance of aquatic vegetation, water quality, and several fish species as food resources for false gharials. Lariman et al., [26] further examined habitat characteristics in the Mesangat Wetlands and reported that false gharials prefer swamp ecosystems with dense vegetation cover, stable water conditions, and abundant fish availability. However, both studies mainly described habitat conditions qualitatively and did not comprehensively analyze fish community structure, biodiversity indices, and ecological relationships between fish assemblages and environmental parameters [27]. In addition, previous ichthyofaunal studies in Indonesian freshwater ecosystems have mostly concentrated on species inventories without specifically evaluating their ecological role in supporting predator habitats such as false gharial ecosystems. Therefore, a scientific gap still exists regarding integrated ecological assessments linking fish biodiversity, aquatic environmental quality, and habitat sustainability of *Tomistoma schlegelii* in tropical freshwater ecosystems.

The novelty of this study lies in the integration of fish biodiversity assessment and environmental characteristics within a false gharial habitat ecosystem. Unlike previous studies that mainly focused on species inventories or crocodilian distribution, this research evaluates fish community structure together with aquatic environmental conditions as ecological support for false gharial survival. The study also provides ecological information regarding freshwater habitat quality through biodiversity indices and physicochemical parameters of the river ecosystem [28], [29]. Such integrated ecological assessment is important for understanding the role of fish communities in maintaining the sustainability of aquatic predator habitats. Therefore, this study contributes valuable baseline data for freshwater biodiversity conservation and false gharial habitat management in tropical river ecosystems.

This study is urgently needed because freshwater ecosystems are currently experiencing increasing ecological pressures from human activities and environmental degradation. Habitat alteration and declining water quality may reduce fish biodiversity and threaten the ecological balance of river ecosystems [30], [31]. The degradation of aquatic habitats may also negatively affect the survival of threatened species such as *Tomistoma schlegelii* through decreased prey availability and habitat suitability [14]. Scientific information regarding fish diversity and environmental conditions is essential for developing evidence-based conservation strategies and sustainable ecosystem management. Therefore, this study aimed to determine fish biodiversity and

aquatic environmental conditions as ecological support for fish communities and the survival of false gharial populations in the false gharial habitat ecosystem.

2. RESEARCH METHOD

2.1. Study Area and Research Period

This study was conducted for three months, from January to March, in the Aek Kundur River ecosystem located in Kebun Pangkatan Sipef Village, Pangkatan Subdistrict, Labuhanbatu Regency, North Sumatra Province, Indonesia. The study area represents a freshwater river ecosystem that is potentially associated with the habitat of the false gharial, *Tomistoma schlegelii*. The river is characterized by tropical freshwater conditions with surrounding riparian vegetation that supports aquatic biodiversity, particularly fish communities [32], [33]. Sampling activities were carried out at several observation stations representing different habitat characteristics along the river ecosystem. The research period was selected to allow adequate observation of fish diversity and environmental conditions within the aquatic habitat.

2.2. Materials and Equipment

The materials and equipment used in this study are presented in Table 1. Several field and laboratory instruments were utilized to support the collection of environmental and ichthyofaunal data within the river ecosystem. Geographic coordinates of each sampling station were determined using a Global Positioning System (GPS). Water quality measurements included water temperature, pH, water transparency, and current velocity using a thermometer, pH meter, Secchi disk, ping-pong ball, measuring rope, and stopwatch. Fish sampling was conducted using fishing nets, fishing rods, and traditional fish traps adjusted to habitat conditions at each observation station. Dissolved oxygen and heavy metal concentrations, including copper (Cu), lead (Pb), mercury (Hg), and manganese (Mn), were analyzed using Atomic Absorption Spectroscopy (AAS), while fish species identification referred to the identification guide by Maurice Kottelat. Documentation activities during the study were supported using a digital camera for recording fish specimens and habitat conditions.

Table 1. Materials and Equipment Used in the Study

No	Parameter	Equipment	Materials
1	Coordinate determination	Global Positioning System	Observation stations
2	Water quality (temperature, pH, transparency, current velocity)	Thermometer, pH meter, Secchi disk, ping-pong ball, measuring rope, stopwatch	Water samples
3	Fish sampling	Gill net (1.5 m × 6 m), fishing rod (2 m), and traditional fish trap (50 cm diameter) adjusted to station conditions	Fish diversity samples
4	Dissolved oxygen and heavy metal analysis (Cu, Pb, Hg, and Mn)	Atomic Absorption Spectroscopy	Water samples
5	Species identification	Fish identification book by Maurice Kottelat in 1993	Fish specimens
6	Documentation	Digital camera	Fish specimens and research locations

2.3. Research Method

This study employed a purposive sampling method to determine observation stations within the river ecosystem. Purposive sampling is a sampling technique in which sampling locations are selected based on specific ecological considerations relevant to the objectives of the study [34], [35]. The selection of sampling stations was carried out by considering habitat characteristics, accessibility, aquatic environmental conditions, and the potential presence of *Tomistoma schlegelii* habitat within the study area. This approach was intended to obtain representative data regarding fish biodiversity and environmental conditions in the freshwater ecosystem [36], [37]. Therefore, purposive sampling enabled more effective assessment of fish community structure and habitat characteristics associated with the ecological sustainability of the river ecosystem.

2.4. Prosedur Penelitian

2.4.1. Determination of Observation Stations

Observation stations were determined based on information regarding the presence of false gharial populations obtained from key informants, particularly local communities living around the river ecosystem. Three sampling stations representing potential false gharial habitats were selected along the Aek Kundur River. The coordinates of each station were recorded using a Global Positioning System (GPS) to ensure spatial accuracy during field observations [38], [39]. The observation stations were located at: Station 1 (99°55'41" E;

2°05'39" N), Station 2 (99°55'55.26" E; 2°05'42.79" N), and Station 3 (99°56'18" E; 2°05'42" N). Coordinate data obtained from the field survey were subsequently used for the preparation of the research location map based on Google Earth imagery.

2.4.2. Fish Sampling Method

Fish sampling was conducted using several fishing gears, including gill nets, fishing rods, traditional traps (durung), and fish pots distributed at several points along the river channel. The selection of sampling gear was adjusted according to habitat conditions and accessibility at each observation station. Sampling activities were carried out once every month during the study period. Captured fish specimens were identified based on external morphological characteristics, including body shape, head morphology, mouth position, fin structure, tail shape, and scale characteristics. Species identification referred to the taxonomic identification guide developed by Kottelat in 1993. The number of individuals from each species was recorded to determine fish community composition and biodiversity indices [40], [41]. Fish specimens representing different species were collected as voucher specimens, while individuals belonging to previously identified species were released back into the river ecosystem to maintain population sustainability. Representative specimens from each species were preserved in 70% alcohol for further identification and verification in the Ecology Laboratory. This procedure was carried out to ensure the accuracy of species identification and minimize taxonomic errors during data analysis.

2.4.3. Species Identification Technique

Fish species identification was conducted through morphological observation of each captured specimen. Identification characters included body shape, head structure, mouth morphology, fin arrangement, tail morphology, and scale patterns. Morphological identification was performed using standard taxonomic references and fish identification keys to ensure accurate classification of species [42], [43]. The identification process was conducted both in the field and laboratory to confirm taxonomic characteristics of collected specimens. This approach was applied to obtain reliable data regarding fish biodiversity within the false gharial habitat ecosystem.

2.4.4. Water Quality Assessment

Water quality observations included measurements of temperature, pH, water transparency, and current velocity. All physicochemical parameters were measured directly in the field (in situ) at each observation station during sampling activities. Water temperature was measured using a thermometer, pH using a portable pH meter, transparency using a Secchi disk, and current velocity using a floating object and stopwatch method. Dissolved oxygen (DO) concentration and heavy metal contents, including copper (Cu), lead (Pb), mercury (Hg), and cadmium (Cd), were analyzed ex situ in the Laboratory of Industrial Research and Standardization (BARISTAN) Medan.

The average values of water quality parameters were presented in tabular form and analyzed using SPSS version 22 software. Correlation analysis between physicochemical parameters and fish biodiversity indices was performed to evaluate the ecological relationship between aquatic environmental conditions and fish community structure in the river ecosystem [44], [45]. The results were subsequently interpreted descriptively to assess environmental suitability for fish diversity and habitat sustainability of the false gharial ecosystem.

Table 2. Water Quality Parameters Measured During the Study

No	Parameter	Unit	Measurement Method	Location
1	Water temperature	°C	In situ	Research site
2	Water pH	-	In situ	Research site
3	Dissolved Oxygen (DO)	mg/L	Ex situ	Laboratory
4	Water transparency	m	In situ	Research site
5	Current velocity	cm/s	In situ	Research site
6	Heavy metal analysis (Cu, Pb, Hg, and Cd)	mg/L	Ex situ	Laboratory

2.5. Data Analysis

The data obtained during the study were analyzed to evaluate fish biodiversity, community structure, species similarity, dominance patterns, and the relationship between aquatic environmental conditions and fish diversity within the false gharial habitat ecosystem. Ecological analyses included the Shannon–Wiener diversity index, evenness index, similarity index, dominance index, and correlation analysis between physicochemical water parameters and fish diversity indices [46], [47]. The results of these analyses were used to assess ecological conditions and habitat suitability for fish communities in the river ecosystem.

2.5.1. Diversity Index (H')

Fish biodiversity was analyzed using the Shannon–Wiener diversity index following the method proposed by Krebs (1978). The diversity index was calculated using the following equation:

$$H' = \sum_{i=1}^S (p_i \ln p_i) \quad \dots (1)$$

The diversity index was interpreted according to the criteria proposed by Wilhm and Dorris in 1968, where ($H' < 1$) indicates low biodiversity, ($1 < H' < 3$) indicates moderate biodiversity, and ($H' > 3$) indicates high biodiversity.

2.5.2. Uniformity Index (J')

Species evenness was calculated to determine the distribution stability of individuals among species within the fish community. The evenness index was calculated according to Krebs (1978) using the following equation:

$$J' = \frac{H'}{\log^2(S)} = \frac{H'}{H_{\text{maks}}} \quad \dots (2)$$

The interpretation of the evenness index followed the criteria of Rappe (2010), where ($0.00 < E \leq 0.50$) indicates low population evenness and stressed communities, ($0.50 < E \leq 0.75$) indicates moderate evenness and unstable communities, and ($0.75 < E \leq 1.00$) indicates high evenness and stable communities.

2.5.3. Similarity Index (IS)

Species similarity among observation stations was analyzed using the similarity index to determine the degree of resemblance in fish community composition between sampling locations. The similarity index was calculated based on Krebs (1978) using the following equation:

$$IS = \frac{2c}{a+b} \times 100\% \quad \dots (3)$$

The similarity values were classified into four categories: 75–100% (very similar), 50–75% (similar), 25–50% (dissimilar), and $\leq 25\%$ (very dissimilar). Dendrogram analysis based on similarity values was performed using Plymouth Routines in Multivariate Ecological Research (PRIMER) version 7 software.

2.5.4. Dominance Index (C)

Species dominance within the fish community was analyzed using the dominance index proposed by Odum (1993). The dominance index was calculated using the following formula:

$$C = \sum_{i=1}^n p_i^2 = \sum_{i=1}^n \left(\frac{n_i}{N} \right)^2 \quad \dots (4)$$

The dominance index ranges from 0 to 1. A value approaching 1 indicates that the community is dominated by one species, whereas a value approaching 0 indicates that no species strongly dominates the community structure.

2.5.5. Correlation Analysis Between Water Quality Parameters and Fish Diversity

Correlation analysis was conducted to evaluate the relationship between physicochemical water quality parameters and fish biodiversity indices. The analysis was performed using SPSS version 22 software. Water quality variables analyzed included temperature, pH, dissolved oxygen, transparency, current velocity, and heavy metal concentrations [48], [49]. Correlation analysis was used to determine whether environmental factors showed positive or negative relationships with fish diversity within the river ecosystem. Since physicochemical characteristics of aquatic environments act as limiting factors for fish survival and distribution [50],

understanding these relationships is important for evaluating habitat suitability and ecological sustainability within the false gharial habitat ecosystem.

3. RESULTS AND DISCUSSION

3.1. Fish Biodiversity Based on Catch Composition

Fish sampling conducted at the three observation stations in the Aek Kundur River resulted in the identification of 14 fish species belonging to several freshwater fish families. The total catch indicated that the river ecosystem supported relatively diverse fish communities associated with tropical freshwater habitats. The highest abundance was recorded for *Oxygaster anomalura* with a total of 188 individuals, followed by *Barbodes schwanenfeldii* (122 individuals), *Aplocheilus panchax* (97 individuals), *Mystacoleucus marginatus* (86 individuals), and *Trichopodus trichopterus* (85 individuals). Other species recorded during the study included *Hemirhamphodon pogonognathus* (69 individuals), *Mystus singaringan* (60 individuals), *Anabas testudineus* (39 individuals), *Hampala macrolepidota* (27 individuals), and *Osteochilus harrisonii* (14 individuals). Species with the lowest abundance were *Channa striata* (3 individuals), *Channa lucius* (2 individuals), and *Monopterus albus* (1 individual).

The dominance of several cyprinid and freshwater swamp-associated fish species indicated that the river ecosystem possessed environmental characteristics suitable for supporting tropical freshwater fish communities. Species such as *Barbodes schwanenfeldii*, *Mystacoleucus marginatus*, and *Osteochilus harrisonii* are commonly associated with lowland rivers and swamp ecosystems characterized by moderate water flow and dense riparian vegetation. In addition, the occurrence of predatory fish species such as *Channa striata*, *Channa lucius*, and *Hampala macrolepidota* suggested the presence of trophic interactions and relatively stable ecological conditions within the river ecosystem. The presence of surface-dwelling species such as *Aplocheilus panchax* and *Hemirhamphodon pogonognathus* further reflected habitat heterogeneity and the availability of microhabitats along the river margins. These findings indicate that the Aek Kundur River provides ecological support for diverse fish assemblages that potentially function as prey resources for the false gharial, *Tomistoma schlegelii*.

The occurrence of fish species with varying ecological niches demonstrated the complexity of aquatic habitat conditions within the study area [51], [52]. Several species identified during the study are known to tolerate low dissolved oxygen concentrations and acidic waters, characteristics commonly found in tropical swamp ecosystems. Species such as *Anabas testudineus* and *Monopterus albus* possess high adaptive capacity to fluctuating environmental conditions, allowing them to survive in marginal habitats. Conversely, species with relatively low abundance may indicate habitat specificity, limited population size, or ecological pressure within certain sections of the river. Overall, the composition of fish communities observed during this study reflects the ecological characteristics of freshwater ecosystems associated with false gharial habitats.

3.2. Diversity Index (H')

The results of fish diversity analysis in the Aek Kundur River showed relatively similar diversity index values among the three observation stations. The Shannon–Wiener diversity index values recorded were 2.224 at Station 1, 2.202 at Station 2, and 2.222 at Station 3 (Table 2). Based on the classification criteria of Wilhm and Dorris in 1968, all stations were categorized as having moderate biodiversity levels. These findings indicate that the river ecosystem supported a relatively balanced fish community structure with moderate ecological stability. The similarity of diversity values among stations suggests that environmental conditions along the river were relatively homogeneous and capable of supporting comparable fish assemblages.

Table 2. Fish Diversity Index in the Aek Kundur River

No	Observation Station	Diversity Index (H')	Category
1	Station 1	2.224	Moderate
2	Station 2	2.202	Moderate
3	Station 3	2.222	Moderate

The moderate diversity observed at all stations was associated with the dominance of small-sized freshwater fish species within the study area. Species such as *Mystacoleucus marginatus*, *Aplocheilus panchax*, *Barbodes schwanenfeldii*, and *Osteochilus harrisonii* were more abundant than larger predatory fish species, including *Channa striata*, *Channa lucius*, and *Hampala macrolepidota*. The relatively high abundance of small-bodied fish may indicate favorable environmental conditions for omnivorous and plankton-feeding species in tropical freshwater ecosystems. In contrast, the lower abundance of predatory fish species may reflect trophic interactions and ecological pressures within the river ecosystem. The dominance of smaller fish species contributed to the moderate diversity level observed across all sampling stations.

Ecologically, the relatively low occurrence of predatory fish species may also be associated with the presence of apex predators within the habitat ecosystem. Previous studies have reported an inverse relationship between the abundance of small fish species and predatory fish populations in freshwater ecosystems, where reduced predator biomass often corresponds with increased abundance of smaller fish species [53], [54]. The low abundance of large predatory fishes in the present study may indicate predation pressure exerted by the false gharial, *Tomistoma schlegelii*, which is known to primarily consume fish as its major food source. The availability of abundant small-sized fish species therefore may represent an important ecological component supporting the feeding requirements and habitat sustainability of false gharial populations within the river ecosystem. Overall, the diversity index results suggest that the Aek Kundur River maintains ecological conditions capable of supporting diverse fish communities and aquatic predator habitats.

3.3. Evenness Index (j')

The analysis of the evenness index showed relatively similar values among the three observation stations in the Aek Kundur River. The highest evenness value was recorded at Station 1 (0.867), followed by Station 2 (0.856) and Station 3 (0.820) (Table 4). Based on the classification criteria proposed by Rappe (2010), all observation stations were categorized as having high population evenness and stable community conditions. These findings indicate that the distribution of individuals among fish species within the river ecosystem was relatively balanced. High evenness values generally reflect ecological conditions where no single species excessively dominates the fish community structure.

Table 4. Evenness Index of Fish Communities in the Aek Kundur River

No	Observation Station	Evenness Index (j')	Category
1	Station 1	0.867	High population evenness, stable community
2	Station 2	0.856	High population evenness, stable community
3	Station 3	0.820	High population evenness, stable community

The relatively high evenness values observed in this study indicate that fish species were distributed proportionally across the observation stations without extreme dominance by particular species. This condition suggests that the river ecosystem possessed habitat characteristics capable of supporting various fish species with different ecological niches. Habitat heterogeneity, including the availability of riparian vegetation, water depth variation, and food resources, may contribute to the balanced distribution of fish populations within the ecosystem [55], [56]. Similar findings were reported in freshwater wetland ecosystems where high evenness values were associated with stable environmental conditions and diverse habitat availability [57], [58]. Therefore, the balanced fish community structure observed in the Aek Kundur River reflects favorable ecological conditions for freshwater biodiversity.

Ecologically, high species evenness is closely associated with community stability and ecosystem resilience against environmental disturbances. According to ecological theory, increasing evenness values indicate that the abundance among species tends to be more uniform and fish distribution becomes more evenly dispersed throughout the habitat. Such conditions may reduce interspecific competition and promote ecological equilibrium within aquatic ecosystems [59], [60]. The relatively stable fish community structure observed during this study may also support the ecological sustainability of the habitat used by the false gharial, *Tomistoma schlegelii*. Consequently, the high evenness values recorded in the Aek Kundur River suggest that the freshwater ecosystem still maintains environmental conditions suitable for supporting both fish biodiversity and aquatic predator habitats.

3.4. Similarity Index (IS)

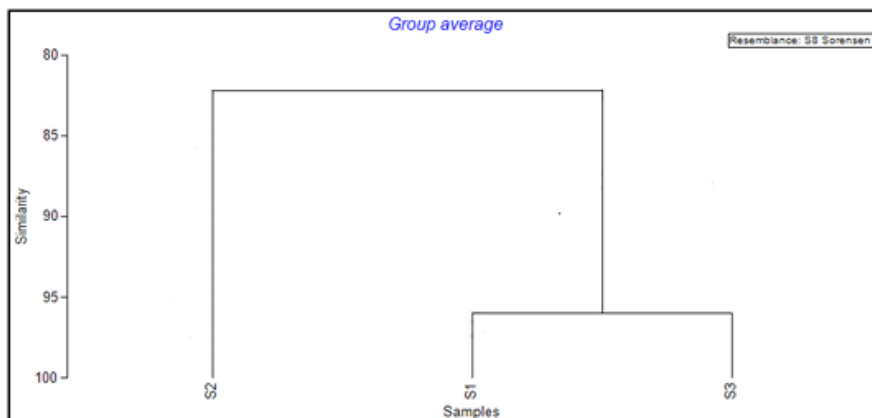
The similarity index analysis showed a high degree of resemblance in fish community composition among the observation stations in the Aek Kundur River. The similarity value between Station 1 and Station 2 was 84.6%, while the similarity between Station 2 and Station 3 reached 80%. The highest similarity value was recorded between Station 1 and Station 3 with a value of 96% (Table 5). Based on the similarity index classification, all observation stations were categorized as very similar because the similarity values exceeded 75%. These findings indicate that the fish communities inhabiting the three stations shared highly comparable species composition and ecological characteristics.

Table 5. Similarity Index of Fish Communities in the Aek Kundur River

Observation Stations	Similarity Index (%)
Station 1 – Station 2	84.6
Station 2 – Station 3	80.0
Station 1 – Station 3	96.0

The high similarity values observed among stations suggest that environmental conditions along the river ecosystem were relatively homogeneous. Similar habitat characteristics such as water flow, riparian vegetation, substrate type, and food availability may contribute to the occurrence of comparable fish assemblages across observation stations. During field observations, dense stands of *Saccharum spontaneum* were commonly found along the riverbanks of the Aek Kundur River. The presence of riparian vegetation is ecologically important because vegetated habitats provide shelter, spawning grounds, and feeding areas for freshwater fish species [61], [62]. Consequently, similar vegetation structure among stations may have influenced the high similarity of fish communities observed in the present study.

Several ecological factors may contribute to the similarity patterns recorded in this study, including habitat size, vegetation cover, environmental stability, and sampling methods used during fish collection. Previous studies have suggested that habitat complexity and riparian vegetation strongly affect fish distribution and community composition in freshwater ecosystems [52], [63]. In addition, the use of similar fishing gears and sampling procedures at each station may have contributed to comparable catch composition among sampling locations. The high degree of similarity among fish communities indicates that the Aek Kundur River ecosystem provides relatively uniform ecological conditions for freshwater fish species. Such habitat consistency may also support the ecological sustainability of the false gharial, *Tomistoma schlegelii*, through stable prey availability within the river ecosystem.



Gambar 1. Similarity Index Dendrogram in Aek Kundur

3.5. Dominance Index (C)

The dominance index analysis showed low dominance values at all observation stations in the Aek Kundur River ecosystem. The dominance index recorded at Station 1 was 0.004, while Stations 2 and 3 each showed a dominance value of 0.003 (Table 6). According to the classification proposed by Odum (1993), dominance index values below 0.05 are categorized as low dominance levels. These results indicate that no single fish species strongly dominated the fish community structure within the study area. Therefore, the fish assemblages observed in the Aek Kundur River can be considered ecologically stable and relatively balanced.

Table 6. Dominance Index of Fish Communities in the Aek Kundur River

No	Observation Station	Dominance Index (C)
1	Station 1	0.004
2	Station 2	0.003
3	Station 3	0.003

The low dominance values observed in this study suggest that fish abundance was distributed relatively evenly among species across all observation stations. Such conditions generally reflect stable ecological interactions and adequate habitat resources within freshwater ecosystems. Although no species exhibited extreme dominance, *Oxygaster anomalura* was the most frequently captured species during the sampling period. The relatively high abundance of this species may be associated with its schooling behavior, which increases the

probability of capture during sampling activities [64], [65]. In addition, the presence of swamp areas and small tributaries connected to the river ecosystem may provide suitable habitat conditions for this species.

Ecologically, low dominance values are commonly associated with balanced trophic interactions and healthy aquatic ecosystems. The absence of dominant species suggests that interspecific competition within the fish community remains relatively stable and that environmental conditions are capable of supporting diverse fish assemblages. Habitat heterogeneity, including riparian vegetation, floodplain areas, and interconnected waterways, likely contributed to the maintenance of community stability in the river ecosystem [66], [67]. These environmental characteristics may also support prey availability for aquatic predators such as the false gharial, *Tomistoma schlegelii*. Therefore, the low dominance index observed in the Aek Kundur River indicates that the freshwater ecosystem still maintains ecological conditions favorable for sustaining fish biodiversity and predator habitat stability.

3.6. Physicochemical Characteristics of Water

The physicochemical parameters measured during the study showed relatively stable environmental conditions across all observation stations in the Aek Kundur River ecosystem. Water temperature ranged from 28–29°C, while water transparency varied between 63–74 cm. Current velocity values ranged from 21–37 cm/s, indicating moderate water flow conditions within the river ecosystem. The pH value at all stations was recorded at 6, reflecting slightly acidic conditions commonly found in tropical freshwater and swamp-associated habitats. Dissolved oxygen (DO) concentrations ranged from 6.4–6.8 mg/L, indicating sufficient oxygen availability to support aquatic organisms and fish communities (Table 7).

Table 7. Average Water Quality Parameters at Each Observation Station

No	Parameter	Unit	Water Quality Standard	Reference	Station 1	Station 2	Station 3
Physical Parameters							
1	Water temperature	°C	28–32	Government Regulation No. 38 of 2011	28	29	28
2	Water transparency	cm	>3 m	Government Regulation No. 38 of 2011	74	63	68
3	Current velocity	cm/s	-	-	21	29	37
Chemical Parameters							
4	pH	Unit	6-9	Government Regulation No. 82 of 2001	6	6	6
5	Dissolved Oxygen (DO)	mg/L	4	Government Regulation No. 82 of 2001	6.4	6.8	6.7
6	Mercury (Hg)	mg/L	0.002	Government Regulation No. 82 of 2001	<0.0008	<0.0008	<0.0008
7	Cadmium (Cd)	mg/L	0.01	Government Regulation No. 82 of 2001	<0.002	<0.002	<0.002
8	Copper (Cu)	mg/L	0.01	Government Regulation No. 82 of 2001	<0.006	<0.006	<0.006
9	Lead (Pb)	mg/L	0.03	Government Regulation No. 82 of 2001	<0.003	<0.003	<0.003

3.6.1. Water Temperature

Water temperature recorded during the study ranged between 28°C and 29°C across all observation stations. Station 1 and Station 3 showed similar temperatures of 28°C, while Station 2 recorded a slightly higher temperature of 29°C. These values fall within the optimal temperature range for tropical freshwater fish species and comply with Indonesian water quality standards. Water temperature plays an important ecological role in regulating aquatic environmental conditions and strongly influences the metabolism, growth, reproduction, and distribution of aquatic organisms [68], [69]. Stable temperature conditions observed in the Aek Kundur River therefore indicate suitable environmental conditions for sustaining freshwater fish biodiversity and aquatic predator habitats.

3.6.2. Water Transparency

The average water transparency values recorded during the study were 74 cm at Station 1, 63 cm at Station 2, and 68 cm at Station 3. Differences in transparency values among stations may be associated with suspended particles and anthropogenic activities occurring around the river ecosystem. During field observations, several areas surrounding the river were influenced by nearby industrial and domestic activities that potentially contributed suspended materials into the aquatic environment [70], [71]. Water transparency is

an important ecological parameter because it affects light penetration, primary productivity, and fish habitat utilization within aquatic ecosystems. The transparency values observed during the study were still considered suitable for supporting fish survival and freshwater ecological processes.

3.6.3. Current Velocity

Current velocity varied among observation stations, with values of 21 cm/s at Station 1, 29 cm/s at Station 2, and 37 cm/s at Station 3. Variations in water current were likely influenced by differences in river morphology, substrate composition, woody debris accumulation, and the presence of stones within each station. Based on river current classification, the observed values indicated slow to moderate flow conditions. Water current plays a significant ecological role in the distribution of dissolved oxygen, nutrients, aquatic organisms, and fish movement patterns within river ecosystems [27], [68]. Moderate current conditions may also contribute to habitat heterogeneity and provide suitable ecological niches for various freshwater fish species.

3.6.4. Potential of Hydrogen (pH)

The pH value recorded at all observation stations was 6, indicating relatively uniform and slightly acidic water conditions throughout the study area. Similar pH values among stations suggest that environmental characteristics along the river ecosystem were relatively homogeneous. According to Indonesian water quality standards, the acceptable pH range for freshwater ecosystems is between 6 and 9, indicating that the pH conditions in the Aek Kundur River remain suitable for aquatic organisms. Slightly acidic conditions are commonly found in tropical freshwater ecosystems associated with organic matter decomposition and swamp vegetation [72], [73]. Stable pH conditions are important because fluctuations in acidity may affect fish physiology, reproduction, and survival within aquatic habitats.

3.6.5. Dissolved Oxygen (DO)

Dissolved oxygen concentrations measured during the study ranged from 6.4 mg/L to 6.8 mg/L across all observation stations. The highest DO concentration was recorded at Station 2 (6.8 mg/L), followed by Station 3 (6.7 mg/L) and Station 1 (6.4 mg/L). These values exceeded the minimum standard of 4 mg/L established for freshwater ecosystems, indicating that the river ecosystem possessed adequate oxygen availability for aquatic life. Dissolved oxygen is one of the most important environmental parameters influencing fish respiration, metabolism, and ecological productivity within freshwater ecosystems [68], [74]. Sufficient oxygen concentrations therefore support fish survival, biodiversity maintenance, and ecological stability within the false gharial habitat ecosystem.

3.6.6. Heavy Metal Concentrations (Hg, Cd, Cu, and Pb)

Laboratory analysis showed that concentrations of mercury (Hg), cadmium (Cd), copper (Cu), and lead (Pb) at all observation stations remained below the maximum permissible limits established by Indonesian water quality standards. Mercury concentrations were recorded at less than 0.0008 mg/L, cadmium at less than 0.002 mg/L, copper at less than 0.006 mg/L, and lead at less than 0.003 mg/L. These results indicate that heavy metal contamination within the river ecosystem was relatively low and did not exceed environmental safety thresholds for aquatic organisms. The low heavy metal concentrations observed during the study may be related to the dominance of agricultural and plantation activities surrounding the research area, where most waste inputs are primarily organic rather than metallic contaminants [75], [76]. Although palm oil processing industries were present near the river ecosystem, their locations were relatively distant from the observation stations, thereby minimizing direct contamination impacts on the study area.

3.7. Correlation Between Physicochemical Parameters and Fish Diversity

The correlation analysis between physicochemical water parameters and fish biodiversity showed varying degrees of ecological relationships among environmental variables. The highest correlation coefficient was observed for water transparency ($r^2 = 0.948$), followed by dissolved oxygen (DO) ($r^2 = 0.460$), current velocity ($r^2 = 0.314$), and water temperature ($r^2 = 0.052$). In contrast, pH and heavy metal concentrations (Hg, Cd, Cu, and Pb) showed correlation values of 0, indicating no measurable relationship with fish diversity during the study period (Table 8). The positive correlation values observed in several environmental parameters indicate that increasing environmental quality was associated with higher fish biodiversity within the river ecosystem.

Table 8. Correlation Between Physicochemical Parameters and Fish Diversity

No	Parameter	r ²
1	Water temperature	0.052
2	Water transparency	0.948
3	Current velocity	0.314
4	pH	0
5	Dissolved Oxygen (DO)	0.460
6	Mercury (Hg)	0
7	Cadmium (Cd)	0
8	Copper (Cu)	0
9	Lead (Pb)	0

Among the measured environmental variables, water transparency showed the strongest correlation with fish biodiversity. High transparency values may enhance light penetration and primary productivity, thereby supporting food availability and habitat suitability for freshwater fish communities. Dissolved oxygen and current velocity also showed moderate correlations with fish diversity, indicating their ecological importance in maintaining aquatic habitat quality and fish distribution patterns. In contrast, pH and heavy metal concentrations did not show significant relationships with fish biodiversity because their values were relatively uniform across all observation stations and remained within acceptable environmental limits.

Ecologically, physicochemical water parameters act as limiting factors that determine the survival, growth, and distribution of aquatic organisms. Favorable environmental conditions may increase habitat suitability and support higher fish biodiversity within freshwater ecosystems. The results of this study indicate that water transparency, dissolved oxygen, current velocity, and temperature were the most influential environmental variables affecting fish biodiversity in the Aek Kundur River. These environmental characteristics are also important for sustaining aquatic food resources required by the false gharial, *Tomistoma schlegelii*. Therefore, maintaining water quality and habitat stability is essential for preserving both fish biodiversity and the ecological sustainability of false gharial habitats within tropical freshwater ecosystems.

The present study demonstrated that the freshwater ecosystem associated with the habitat of the false gharial, *Tomistoma schlegelii*, supported relatively diverse fish communities characterized by moderate diversity, high evenness, high inter-station similarity, and low dominance values. The occurrence of 15 fish species within the study area indicates that the river ecosystem still maintains ecological conditions capable of supporting freshwater biodiversity and trophic interactions. Tropical river ecosystems with stable physicochemical conditions generally exhibit moderate to high fish diversity due to the availability of food resources, habitat heterogeneity, and riparian vegetation complexity [77], [78]. Similar findings have been reported in tropical peat swamp and lowland river ecosystems in Southeast Asia, where freshwater fish communities are strongly influenced by environmental stability and habitat structure. The relatively balanced fish community structure observed in this study therefore suggests that the river ecosystem remains ecologically functional for sustaining aquatic biodiversity.

The dominance of small-bodied fish species such as *Oxygaster anomalura*, *Mystacoleucus marginatus*, *Barbodes schwanefeldii*, and *Aplocheilus panchax* indicates that the aquatic habitat provides favorable conditions for omnivorous and planktivorous freshwater fishes. Small-sized fish species are generally more adaptable to fluctuating environmental conditions and often dominate tropical freshwater ecosystems with moderate environmental productivity [79], [80]. In contrast, predatory fish species such as *Channa striata*, *Channa lucius*, and *Hampala macrolepidota* were recorded in lower abundance. Ecologically, this condition may reflect trophic interactions within the aquatic food web, including predation pressure exerted by higher predators occupying the ecosystem. Previous ecological studies have shown that the reduction of predatory fish abundance may increase the population size of smaller prey fishes due to reduced competition and predation among fish communities [81], [82]. Consequently, the abundance of small fish species in the present study may represent an important prey resource supporting the feeding ecology of the false gharial within tropical freshwater ecosystems.

The moderate diversity index values observed at all observation stations suggest that the river ecosystem possessed relatively stable environmental conditions without severe ecological disturbances. Shannon–Wiener diversity values ranging from 2.202 to 2.224 indicate that fish species distribution within the ecosystem remained relatively balanced. Similar diversity levels have frequently been reported in tropical freshwater rivers influenced by swamp vegetation and moderate water flow conditions. Environmental heterogeneity, including variations in riparian vegetation, water depth, and substrate composition, may contribute to the maintenance of fish diversity in freshwater ecosystems [55], [56]. In addition, the relatively high evenness values recorded during the study indicate that fish abundance was distributed proportionally among species, thereby reflecting stable ecological interactions within the aquatic habitat. High evenness values

are commonly associated with ecosystems possessing sufficient habitat resources and relatively low environmental stress.

The high similarity index values among observation stations indicate that fish communities within the study area shared highly comparable ecological characteristics and habitat conditions. Similarity values exceeding 80% suggest that environmental variables along the river ecosystem were relatively homogeneous and supported comparable fish assemblages. The presence of dense riparian vegetation, particularly *Saccharum spontaneum*, may have contributed substantially to habitat uniformity and fish community stability. Riparian vegetation plays important ecological roles in tropical freshwater ecosystems by providing shelter, spawning habitats, feeding grounds, and protection against predators [83], [84]. Vegetated river margins may also contribute organic matter and nutrients into aquatic ecosystems, thereby enhancing food-web productivity and supporting aquatic biodiversity. Consequently, the high similarity among fish communities observed in the study likely reflects the ecological continuity of habitat conditions throughout the river system.

The low dominance index values recorded at all observation stations further indicate that the river ecosystem maintains relatively balanced community dynamics without excessive species dominance [85], [86]. Low dominance values generally reflect stable ecological conditions where resource availability and habitat quality are sufficient to support multiple species simultaneously. Although *Oxygaster anomalura* was the most abundant species recorded during the study, its dominance remained within ecologically balanced levels. The schooling behavior of this species likely contributed to its relatively high capture frequency during sampling activities. In tropical freshwater ecosystems, schooling fish species commonly occupy open-water habitats and play important roles in trophic energy transfer between lower and higher trophic levels. Therefore, the abundance of schooling fish species within the study area may contribute significantly to ecosystem productivity and prey availability for aquatic predators such as the false gharial.

The physicochemical characteristics measured during the study indicate that the aquatic environment remains suitable for sustaining freshwater biodiversity. Water temperature values ranging from 28–29°C fall within the optimal range for tropical freshwater fish metabolism, growth, and reproductive processes. Stable temperature conditions are essential for maintaining physiological performance and ecological interactions within aquatic ecosystems. Similarly, dissolved oxygen concentrations exceeding 6 mg/L indicate adequate oxygen availability for aquatic organisms and suggest relatively good water quality conditions. Dissolved oxygen is one of the most critical environmental variables regulating fish respiration, metabolism, and survival, particularly in tropical freshwater ecosystems where oxygen fluctuations may occur due to organic decomposition and hydrological variability [87], [88]. The slightly acidic pH conditions observed in the study area are also characteristic of tropical swamp-associated freshwater ecosystems and remain within tolerable ranges for most freshwater fish species.

Correlation analysis demonstrated that water transparency exhibited the strongest relationship with fish biodiversity compared to other environmental variables. High transparency values may improve light penetration and increase primary productivity within aquatic ecosystems, thereby supporting food availability for freshwater organisms. Dissolved oxygen and current velocity also showed moderate correlations with fish diversity, indicating that hydrological and oxygen conditions are important ecological drivers influencing fish distribution and habitat utilization. In contrast, heavy metal concentrations and pH values showed no significant correlation with biodiversity because their concentrations remained relatively uniform and below environmental safety thresholds across all stations. The low heavy metal concentrations observed during the study suggest minimal industrial contamination within the river ecosystem [89], [90]. This condition is ecologically important because heavy metal accumulation may negatively affect fish physiology, reproductive success, and community structure in freshwater environments.

From a conservation perspective, the findings of this study highlight the ecological importance of maintaining habitat quality within false gharial ecosystems. The false gharial is recognized as one of the most threatened crocodylian species globally, with habitat degradation and prey reduction representing major threats to its survival. The availability of diverse fish communities within the river ecosystem therefore represents a critical ecological component supporting the sustainability of false gharial populations. Freshwater habitat degradation, pollution, deforestation, and hydrological alteration may directly reduce prey availability and negatively affect crocodylian population persistence. Consequently, maintaining water quality, riparian vegetation, and aquatic biodiversity should become a priority in conservation management strategies aimed at protecting tropical freshwater ecosystems and false gharial habitats.

Overall, the present study provides important ecological information regarding fish biodiversity and environmental conditions within tropical freshwater habitats associated with the false gharial. The integration of fish community analysis and physicochemical assessment contributes to a broader understanding of trophic interactions and habitat suitability within freshwater ecosystems. These findings may serve as baseline ecological data for future biodiversity monitoring, aquatic ecosystem management, and conservation planning for false gharial habitats in tropical river systems.

The findings of this study have important ecological and conservation implications for the management of tropical freshwater ecosystems associated with false gharial habitats, *Tomistoma schlegelii*. The relatively stable fish community structure and favorable physicochemical water conditions observed in the Aek Kundur River indicate that the ecosystem still possesses ecological capacity to support aquatic biodiversity and trophic sustainability. These results may contribute to the development of habitat-based conservation strategies by emphasizing the importance of maintaining fish biodiversity, water quality, and riparian vegetation within freshwater ecosystems inhabited by the false gharial. Furthermore, the study provides baseline ecological information that can support future biodiversity monitoring, freshwater management programs, and conservation planning for threatened crocodylian species in Indonesia. The integration of fish biodiversity assessment and environmental quality analysis also highlights the importance of ecosystem-based approaches in freshwater conservation research.

Despite these contributions, several limitations should be acknowledged in the present study. First, the sampling period was relatively short and conducted within a limited temporal scale, which may not fully represent seasonal fluctuations in fish community dynamics and environmental conditions. Second, the study was restricted to three observation stations within a single river ecosystem, thereby limiting broader spatial generalization to other tropical freshwater habitats. Third, the ecological relationship between fish biodiversity and false gharial feeding ecology was inferred indirectly based on habitat association and prey availability rather than direct dietary analysis. In addition, more advanced ecological analyses such as multivariate statistics, trophic interaction modeling, and long-term population monitoring were not included in the present study. Therefore, future research should incorporate broader spatial coverage, seasonal sampling, molecular identification approaches, and ecological modeling to provide a more comprehensive understanding of freshwater biodiversity dynamics and false gharial habitat sustainability.

4. CONCLUSION

This study revealed that the Aek Kundur River ecosystem supports relatively diverse fish communities that potentially function as prey resources for the false gharial (*Tomistoma schlegelii*). A total of 15 fish species were identified during the study, namely *Bagrus nemurus*, *Notopterus notopterus*, *Monopterus albus*, *Anabas testudineus*, *Channa striata*, *Channa lucius*, *Hampala macrolepidota*, *Mystacoleucus marginatus*, *Aplocheilichthys panchax*, *Barbodes schwanenfeldii*, *Osteochilus harrisonii*, *Mystus singaringan*, *Trichopodus trichopterus*, *Oxygaster anomalura*, and *Hemirhamphodon pogonognathus*. The fish community structure showed moderate diversity, high evenness, high similarity among stations, and low dominance levels, indicating relatively stable ecological conditions within the river ecosystem. The dominance of small-bodied freshwater fish species suggests the availability of prey resources that may support the feeding ecology of the false gharial. Overall, the biodiversity characteristics observed in this study indicate that the Aek Kundur River remains an important freshwater habitat supporting fish assemblages and aquatic predator sustainability.

The physicochemical characteristics of the Aek Kundur River were generally suitable for supporting fish survival and freshwater ecosystem stability. Water temperature ranged from 28–29°C, water transparency from 63–74 cm, current velocity from 21–37 cm/s, pH remained at 6, dissolved oxygen concentrations ranged from 6.4–6.8 mg/L, and heavy metal concentrations of Hg, Cd, Cu, and Pb remained below the environmental quality standards established for freshwater ecosystems. Correlation analysis demonstrated positive relationships between several environmental parameters and fish biodiversity, indicating that improved water quality was associated with higher fish diversity. Among the measured variables, water transparency (0.948), dissolved oxygen (0.460), current velocity (0.314), and water temperature (0.052) were identified as the most influential physicochemical factors affecting fish biodiversity in the river ecosystem. These findings suggest that maintaining environmental quality and habitat stability is essential for conserving freshwater biodiversity and sustaining habitats of the false gharial, *Tomistoma schlegelii*, in tropical river ecosystems. Future studies are recommended to incorporate seasonal sampling and broader spatial coverage to better understand temporal variations in fish biodiversity and habitat dynamics within false gharial ecosystems, *Tomistoma schlegelii*. In addition, further research integrating trophic analysis, molecular identification, and advanced multivariate ecological approaches is needed to provide a more comprehensive understanding of predator–prey interactions and freshwater ecosystem sustainability.

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AUTHOR CONTRIBUTIONS

Conceptualization, I.H. and T.R.; Methodology, I.H. and J.K.; Software, I.H.; Validation, T.R. and J.K.; Formal Analysis, I.H.; Investigation, I.H.; Resources, T.R.; Data Curation, I.H.; Writing – Original Draft Preparation, I.H.; Writing – Review & Editing, T.R. and J.K.; Visualization, I.H.; Supervision, T.R.; Project Administration, I.H.; Funding Acquisition, T.R.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

REFERENCES

- [1] M. L. Piczak *et al.*, “Protecting and restoring habitats to benefit freshwater biodiversity,” *Environ. Rev.*, vol. 32, no. 3, pp. 438–456, 2024, doi: 10.1139/er-2023-0034.
- [2] D. Nimma *et al.*, “Implications of climate change on freshwater ecosystems and their biodiversity,” *Desalin. Water Treat.*, vol. 321, pp. 1–9, 2025, doi: 10.1016/j.dwt.2024.100889.
- [3] A. M. Torres-Bejarano, S. M. P. Sullivan, W. González-Daza, C. Cáceres, and G. J. Colorado Z., “Riparian vegetation structure and seasonality influence functional diversity more than taxonomic diversity of stream fish assemblages in the Colombian Amazon,” *Aquat. Ecol.*, vol. 56, no. 1, pp. 153–172, Mar. 2022, doi: 10.1007/s10452-021-09904-y.
- [4] W. K. Dodds *et al.*, “Defining stream riparian zones across multidimensional environmental gradients,” *J. Environ. Qual.*, vol. 54, no. 6, pp. 1674–1697, 2025, doi: 10.1002/jeq2.70080.
- [5] F. Stefani *et al.*, “Response of functional diversity of fish communities to habitat alterations in small lowland rivers,” *Biodivers. Conserv.*, vol. 33, no. 4, pp. 1439–1458, 2024, doi: 10.1007/s10531-024-02809-w.
- [6] S. Chen *et al.*, “Channelization and flow depletion shift benthic macroinvertebrate and fish communities in urban rivers,” *PLoS One*, vol. 20, no. 7 July, pp. 1–16, 2025, doi: 10.1371/journal.pone.0328843.
- [7] G. T. Jerônimo, M. G. da Cruz, E. de A. Bertaglia, W. E. Furtado, and M. L. Martins, “Fish parasites can reflect environmental quality in fish farms,” *Rev. Aquac.*, vol. 14, no. 3, pp. 1558–1571, Jun. 2022, doi: 10.1111/raq.12662.
- [8] D. D. Colombano, S. M. Carlson, J. A. Hobbs, and A. Ruhi, “Four decades of climatic fluctuations and fish recruitment stability across a marine-freshwater gradient,” *Glob. Chang. Biol.*, vol. 28, no. 17, pp. 5104–5120, 2022, doi: 10.1111/gcb.16266.
- [9] S. K. Chakraborty, P. Sanyal, and R. Ray, “Pollution, Environmental Perturbation and Consequent Loss of Wetlands,” in *Wetlands Ecology*, Cham: Springer International Publishing, 2023, pp. 521–582. doi: 10.1007/978-3-031-09253-4_8.
- [10] M. M. Rahman, A. Burian, T. J. Creedy, and A. P. Vogler, “DNA-based assessment of environmental degradation in an unknown fauna: The freshwater macroinvertebrates of the Indo-Burmese hotspot,” *J. Appl. Ecol.*, vol. 59, no. 6, pp. 1644–1658, Jun. 2022, doi: 10.1111/1365-2664.14174.
- [11] I. Nadya *et al.*, “Assessing fish alpha diversity in relation to water quality parameters in mendelang river, Merangin, Jambi,” *Indones. J. Limnol.*, vol. 6, no. 2, pp. 82–95, Dec. 2025, doi: 10.51264/inajl.v6i2.94.
- [12] S. K. Chakraborty, P. Sanyal, and R. Ray, “Ecosystem Services and Values of Wetlands with Special Reference with East Kolkata Wetlands,” in *Wetlands Ecology*, Cham: Springer International Publishing, 2023, pp. 227–255. doi: 10.1007/978-3-031-09253-4_4.
- [13] M. S. Bors and J. Gruszczynska, “Trends in genetic markers in crocodylian conservation genetics,” *Folia Pomeranae Univ. Technol. Stetin. Agric. Aliment. Piscaria Zootech.*, vol. 375, no. 74, pp. 1–21, 2025, doi: 10.21005/aapz2025.74.2.1.
- [14] B. Sideleau, A. Staniewicz, M. Syah, and K. J. Shaney, “An analysis of tomistoma (*tomistoma schlegelii*) attacks on humans,” *Mar. Freshw. Res.*, vol. 73, no. 11, pp. 1331–1338, Oct. 2022, doi: 10.1071/MF22015.
- [15] M. Santiago-Plata *et al.*, “Genetic diversity, demographic parameters, and trophic ecology of the pampas cat (*leopardus garleppi*) in a Ramsar wetland of Northwestern Peru,” *Genes (Basel)*, vol. 17, no. 3, pp. 1–27, 2026, doi: 10.3390/genes17030320.
- [16] I. Abedin, H. Singha, S. Singh, T. Mukherjee, H. W. Kim, and S. Kundu, “Riverine realities: Evaluating climate change impacts on habitat dynamics of the critically endangered gharial (*Gavialis gangeticus*) in the Indian landscape,” *Animals*, vol. 15, no. 6, pp. 1–20, 2025, doi: 10.3390/ani15060896.
- [17] A. Pathak *et al.*, “Understanding the perception of buffer zone communities to gharial (*Gavialis gangeticus*) conservation in Chitwan National Park, Nepal,” *Glob. Ecol. Conserv.*, vol. 47, pp. 1–10, 2023, doi: 10.1016/j.gecco.2023.e02634.
- [18] L. P. Rath, S. K. Dash, R. K. Mohapatra, A. Patnaik, A. Khan, and S. Maharana, “Exploring the human dimensions of gharial conservation in the Mahanadi River, India,” *Wildl. Res.*, vol. 52, no. 3, pp. 1–10, Mar. 2025, doi: 10.1071/WR24088.
- [19] V. Kamboj, N. Kamboj, A. K. Sharma, and A. Bisht, “Fish diversity associated with environmental parameters in impacted area of Ganga River, India,” *Proc. Natl. Acad. Sci. India Sect. B Biol. Sci.*, vol. 93, no. 1, pp. 79–90, Mar. 2023, doi: 10.1007/s40011-022-01393-9.
- [20] D. S. Malik *et al.*, “Anthropogenic Impact on Fish Faunal Diversity and Their Habitat Ecology in the Ganga River and Its Tributaries, Uttarakhand,” 2022, pp. 53–71. doi: 10.1007/978-3-031-05335-1_4.
- [21] H. Chawla, S. K. Singh, and A. K. Haritash, “Reversing the damage: Ecological restoration of polluted water bodies affected by pollutants due to anthropogenic activities,” *Environ. Sci. Pollut. Res.*, vol. 31, no. 1, pp. 127–143, Dec. 2023, doi: 10.1007/s11356-023-31295-w.

- [22] M. Padhiary and R. Kumar, "Assessing the Environmental Impacts of Agriculture, Industrial Operations, and Mining on Agro-Ecosystems," 2024, pp. 107–126. doi: 10.1007/978-3-031-70102-3_8.
- [23] D. Bănăduc *et al.*, "Freshwater as a sustainable resource and generator of secondary resources in the 21st century: Stressors, threats, risks, management and protection strategies, and conservation approaches," *Int. J. Environ. Res. Public Health*, vol. 19, no. 24, pp. 1–29, 2022, doi: 10.3390/ijerph192416570.
- [24] T. Erős, V. Hermoso, and S. D. Langhans, "Leading the path toward sustainable freshwater management: Reconciling challenges and opportunities in historical, hybrid, and novel ecosystem types," *Wiley Interdiscip. Rev. Water*, vol. 10, no. 3, pp. 1–13, 2023, doi: 10.1002/wat2.1645.
- [25] M. B. Saputro, S. Rifanjani, and S. Siahaan, "Study of senyulong crocodile (*tomistoma schlegelii*) habitat in sekonyer river tanjung puting national park central kalimantan," *J. Hutan Lestari*, vol. 8, no. 1, pp. 145–155, 2020, doi: 10.26418/jhl.v8i1.39389.
- [26] L. Lariman, M. Desyana, and S. Trimurti, "Study of false gharial (*tomistoma schlegelii*) habitat characteristics in mesang wetlands, east kutai, east kalimantan," *Int. J. Sci. Res.*, vol. 10, no. 12, pp. 649–653, 2021, doi: 10.21275/sr211208061717.
- [27] S. O. Ongh *et al.*, "Fish community structure in accordance with environmental signatures in a tropical river ecosystem in the Eastern Himalayan ecoregion," *Aquat. Sci.*, vol. 87, no. 2, pp. 1–17, 2025, doi: 10.1007/s00027-025-01169-z.
- [28] D. S. Malik and P. Rath, "The influence of physico-chemical parameters on habitat ecology and assemblage structure of freshwater phytoplankton in tehri reservoir garhwal (uttarakhand) India," in *Proceedings of the National Academy of Sciences, India Section B: Biological Sciences*, Sep. 2022, pp. 541–551. doi: 10.1007/s40011-021-01313-3.
- [29] J. Das and J. Maity, "Assessing the health of freshwater ecosystems: The role of biomonitoring scores and diversity indices in evaluating aquatic insect populations," *J. Appl. Entomol.*, vol. 5, no. 2, pp. 1–10, 2025, doi: 10.64171/jae.5.2.1-10.
- [30] E. Seren and A. Celekli, "Biodiversity loss: A global issue threatening ecological balance," in *ICHEAS 7th International Conference on Health, Engineering, and Applied Sciences*, 2024, pp. 83–98.
- [31] P. Li, D. Li, X. Sun, Z. Chu, T. Xia, and B. Zheng, "Application of ecological restoration technologies for the improvement of biodiversity and ecosystem in the river," *Water (Switzerland)*, vol. 14, no. 9, pp. 1–16, 2022, doi: 10.3390/w14091402.
- [32] J. J. Morales, L. Mateus, L. Peluso, P. Zeilhofer, B. R. S. Figueiredo, and J. Penha, "Increasing agricultural land use in riparian networks negatively affects stream fish communities in a tropical savanna," *Hydrobiologia*, vol. 852, no. 1, pp. 185–200, Jan. 2025, doi: 10.1007/s10750-024-05697-x.
- [33] T. Stoffers, A. D. Buijse, J. J. Poos, J. A. J. Verreth, and L. A. J. Nagelkerke, "Ontogenetic shifts by juvenile fishes highlight the need for habitat heterogeneity and connectivity in river restoration," *Limnol. Oceanogr.*, vol. 70, no. 3, pp. 732–748, 2025, doi: 10.1002/lno.12797.
- [34] O. Tajik, J. Golzar, and S. Noor, "Purposive sampling," *Int. J. Educ. Lang. Stud.*, vol. 2, no. 2, pp. 1–9, 2024.
- [35] N. Dahal *et al.*, "Participant selection procedures in qualitative research: experiences and some points for consideration," *Front. Res. Metrics Anal.*, vol. 9, pp. 1–13, 2024, doi: 10.3389/frma.2024.1512747.
- [36] M. Pinna *et al.*, "An overview of ecological indicators of fish to evaluate the anthropogenic pressures in aquatic ecosystems: From traditional to innovative DNA-based approaches," *Water (Switzerland)*, vol. 15, no. 5, pp. 1–21, 2023, doi: 10.3390/w15050949.
- [37] S. G. Jarvis *et al.*, "Integrating freshwater biodiversity data sources: Key challenges and opportunities," *Freshw. Biol.*, vol. 68, no. 9, pp. 1479–1488, 2023, doi: 10.1111/fwb.14143.
- [38] I. Ashour, M. El Tokhey, Y. Mogahed, and A. Ragheb, "Performance of global navigation satellite systems (GNSS) in absence of GPS observations," *Ain Shams Eng. J.*, vol. 13, no. 2, pp. 1–7, 2022, doi: 10.1016/j.asej.2021.09.016.
- [39] M. Steuer, R. Burdzik, and F. Piednoir, "Implementation of global navigation satellite systems in railway traffic control systems: Overview of navigation systems, application areas, and implementation plans," *Appl. Sci.*, vol. 15, no. 1, pp. 1–33, 2025, doi: 10.3390/app15010356.
- [40] C. Duarte, L. H. Antão, A. E. Magurran, and C. P. de Deus, "Shifts in fish community composition and structure linked to seasonality in a tropical river," *Freshw. Biol.*, vol. 67, no. 10, pp. 1789–1800, Oct. 2022, doi: 10.1111/fwb.13975.
- [41] Z. Luo *et al.*, "Relationships between fish community structure and environmental factors in the nearshore waters of hainan island, South China," *Diversity*, vol. 15, no. 8, pp. 1–17, 2023, doi: 10.3390/d15080901.
- [42] V. C. Fuentes *et al.*, "An automated method inspired by taxonomic classification for distinguishing chilean pelagic fish species," *IEEE Access*, vol. 13, no. June, pp. 128447–128464, 2025, doi: 10.1109/ACCESS.2025.3590378.
- [43] K. Silambarasan, P. Senthilkumaar, A. Sundaramanickam, and A. Preti, "Identification of larval fishes in tropical estuarine waters using morphology and DNA barcoding methods (Alamparai, India)," *Genet. Aquat. Org.*, vol. 10, no. 2, pp. 1–13, 2026, doi: 10.4194/GA911.
- [44] M. M. Qian *et al.*, "Environmental DNA unveiling the fish community structure and diversity features in the Yangtze River basin," *Environ. Res.*, vol. 239, no. P1, pp. 1–10, 2023, doi: 10.1016/j.envres.2023.117198.
- [45] S. Bi *et al.*, "Spatio-temporal variation of bacterioplankton community structure in the Pearl River: impacts of artificial fishery habitat and physicochemical factors," *BMC Ecol. Evol.*, vol. 22, no. 1, pp. 1–13, 2022, doi: 10.1186/s12862-022-01965-3.
- [46] K. P. Devi and S. Jahan, "Diversity, richness, evenness and dominance index fishes in Ami River Water, Gorakhpur, Uttar Pradesh, India," *J. Curr. Res. Stud.*, vol. 02, no. 01, pp. 9–15, 2024.
- [47] S. K. Das *et al.*, "Effect of environmental drivers of fish assemblage and diversity patterns in temporal scale in Mongra Reservoir: A case study from one of the tributaries of Mahanadi Basin, Central India," *Ecohydrology*, vol. 16, no. 8, pp. 1–9, Dec. 2023, doi: 10.1002/eco.2599.
- [48] Y. Zou *et al.*, "Predictions of heavy metal concentrations by physiochemical water quality parameters in coastal areas of Yangtze river estuary," *Mar. Pollut. Bull.*, vol. 199, pp. 1–14, Feb. 2024, doi: 10.1016/j.marpolbul.2023.115951.

- [49] M. K. Poshtegal and S. A. Mirbagheri, "Simulation and modelling of heavy metals and water quality parameters in the river," *Sci. Rep.*, vol. 13, no. 1, pp. 1–20, 2023, doi: 10.1038/s41598-023-29878-1.
- [50] S. V. Menon *et al.*, "Water physicochemical factors and oxidative stress physiology in fish, a review," *Front. Environ. Sci.*, vol. 11, no. September, pp. 1–26, 2023, doi: 10.3389/fenvs.2023.1240813.
- [51] A. Jan, I. Arismendi, and G. Giannico, "Double trouble for native species under climate change: Habitat loss and increased environmental overlap with non-native species," *Glob. Chang. Biol.*, vol. 31, no. 1, pp. 1–31, 2025, doi: 10.1111/gcb.70040.
- [52] P. R. Soukup, J. Näslund, J. Höjesjö, and D. S. Boukal, "From individuals to communities: Habitat complexity affects all levels of organization in aquatic environments," *WIREs Water*, vol. 9, no. 1, pp. 1–18, Jan. 2022, doi: 10.1002/wat2.1575.
- [53] J. Burbank *et al.*, "Substantial loss of trawlable biomass and lack of recovery in a marine ecosystem," *Commun. Biol.*, vol. 8, no. 1, pp. 1–11, 2025, doi: 10.1038/s42003-025-08240-3.
- [54] Z. Mao, Y. Cao, X. Gu, Q. Zeng, H. Chen, and E. Jeppesen, "Response of zooplankton to nutrient reduction and enhanced fish predation in a shallow eutrophic lake," *Ecol. Appl.*, vol. 33, no. 1, pp. 1–10, Jan. 2023, doi: 10.1002/eap.2750.
- [55] C. Liao *et al.*, "Tributaries create habitat heterogeneity and enhance fish assemblage variation in one of the largest reservoirs in the world," *Hydrobiologia*, vol. 850, no. 19, pp. 4311–4326, Nov. 2023, doi: 10.1007/s10750-023-05306-3.
- [56] X. Shi and R. Czerniawski, "Habitat heterogeneity and channelization of small rivers and streams: Fish community responses to ecological gradients," *Ecol. Evol.*, vol. 15, no. 9, pp. 1–10, Sep. 2025, doi: 10.1002/eec3.72092.
- [57] A. Song, S. Liang, H. Li, and B. Yan, "Effects of biodiversity on functional stability of freshwater wetlands: a systematic review," *Front. Microbiol.*, vol. 15, no. April, pp. 1–10, 2024, doi: 10.3389/fmicb.2024.1397683.
- [58] S. A. Sanjay and B. V. Ramdas, "Comparative assessment of vertebrate biodiversity across major ecosystems of maharashtra," *Int. J. Res. Technol. Int.*, vol. 13, no. 04, pp. 1237–1250, 2025.
- [59] H. Lin, D. Wang, Q. Wang, J. Mao, Y. Bai, and J. Qu, "Interspecific competition prevents the proliferation of social cheaters in an unstructured environment," *ISME J.*, vol. 18, no. 1, pp. 1–12, 2024, doi: 10.1093/ismejo/wrad038.
- [60] L. da Costa, L. A. Vieira, T. S. Michelan, A. H. Vale, and W. A. Chiba de Castro, "Growth allocation shifts in the invasive hydrilla verticillata under interspecific competition with native submerged macrophytes," *Plants*, vol. 13, no. 24, pp. 1–13, 2024, doi: 10.3390/plants13243500.
- [61] Z. Mao *et al.*, "The classification of riparian habitats and assessment of fish-spawning habitat suitability: A case study of the three gorges reservoir, China," *Sustain.*, vol. 15, no. 17, pp. 1–15, 2023, doi: 10.3390/su151712773.
- [62] H. O. Mangi, "Water level fluctuation effect on fish reproduction success," *Int. J. Ecol.*, vol. 2024, pp. 1–13, Apr. 2024, doi: 10.1155/2024/4876582.
- [63] E. S. F. Medeiros, M. J. da Silva, T. P. A. Ramos, and R. T. C. Ramos, "Environmental variables as predictors of fish community composition in semiarid aquatic systems," *Acta Limnol. Bras.*, vol. 36, no. 4, pp. 1–13, 2024, doi: 10.1590/S2179-975X3023.
- [64] M. Zaman, N. J. Roberts, M. Zhu, K. Vitekere, M. Wang, and G. Jiang, "Temporal activity patterns of North China leopards and their prey in response to moonlight and habitat factors," *Ecol. Evol.*, vol. 12, no. 6, pp. 1–14, Jun. 2022, doi: 10.1002/eec3.9032.
- [65] J. P. Newton, M. E. Allentoft, P. W. Bateman, M. van der Heyde, and P. Nevill, "Targeting terrestrial vertebrates with eDNA: Trends, perspectives, and considerations for sampling," *Environ. DNA*, vol. 7, no. 1, pp. 1–18, Jan. 2025, doi: 10.1002/edn3.70056.
- [66] M. P. Graziano, A. K. Deguire, and T. D. Surasinghe, "Riparian buffers as a critical landscape feature: Insights for riverscape conservation and policy renovations," *Diversity*, vol. 14, no. 3, pp. 1–20, 2022, doi: 10.3390/d14030172.
- [67] M. Henriques, T. R. McVicar, K. L. Holland, and E. Daly, "Riparian vegetation and geomorphological interactions in anabranching rivers: A global review," *Ecohydrology*, vol. 15, no. 2, pp. 1–10, Mar. 2022, doi: 10.1002/eco.2370.
- [68] A. Marium, A. M. M. Chatha, S. Naz, M. F. Khan, W. Safdar, and I. Ashraf, "Effect of temperature, pH, salinity and dissolved oxygen on fishes," *J. Zool. Syst.*, vol. 1, no. 2, pp. 1–12, 2023, doi: 10.56946/jzs.v1i2.198.
- [69] D. Agarwal, S. A. Shanmugam, A. Kathirvelpandian, S. Eswaran, M. A. Rather, and G. Rakkannan, "Unraveling the impact of climate change on fish physiology: A focus on temperature and salinity dynamics," *J. Appl. Ichthyol.*, vol. 2024, no. 1, pp. 1–19, Jan. 2024, doi: 10.1155/2024/5782274.
- [70] N. Imam, A. S. El-Shamy, G. S. Abdelaziz, and D. M. Belal, "Influence of the industrial pollutant on water quality, radioactivity levels, and biological communities in Ismailia Canal, Nile River, Egypt," *Environ. Sci. Pollut. Res.*, vol. 31, no. 18, pp. 26855–26879, Mar. 2024, doi: 10.1007/s11356-024-32672-9.
- [71] M. M. Khalil, S. M. Aboueldahab, K. H. M. Abdel-Raheem, M. Ahmed, M. S. Ahmed, and A. A. Abdelhady, "Mixed agricultural, industrial, and domestic drainage water discharge poses a massive strain on freshwater ecosystems: A case from the Nile River in Upper Egypt," *Environ. Sci. Pollut. Res.*, vol. 30, no. 58, pp. 122642–122662, Nov. 2023, doi: 10.1007/s11356-023-30994-8.
- [72] C. Dalton, J. J. Imbrogno, M. M. McCue, R. A. Easley, Y. Y. J. Tong, and D. Chen, "The effects of soil moisture and pH on soil organic carbon content in tidal freshwater marsh wetlands," *J. Freshw. Ecol.*, vol. 40, no. 1, pp. 1–14, 2025, doi: 10.1080/02705060.2025.2465403.
- [73] E. Cejudo, M. E. Hernández, A. Campos, D. Infante-Mata, and P. Moreno-Casasola, "Leaf litter production and soil carbon storage in forested freshwater wetlands and mangrove swamps in Veracruz, Gulf of Mexico," *Mires Peat*, vol. 28, pp. 1–29, 2022, doi: 10.19189/MaP.2020.OMB.StA.1994.
- [74] S. Kumar, T. Paul, P. Sarkar, and K. Kumar, "Environmental Factors Affecting Aquatic Animal Health," in *Management of Fish Diseases*, Singapore: Springer Nature Singapore, 2025, pp. 171–188. doi: 10.1007/978-981-96-0270-4_7.

- [75] C. Yao *et al.*, “Heavy metal pollution in agricultural soils from surrounding industries with low emissions: Assessing contamination levels and sources,” *Sci. Total Environ.*, vol. 917, no. January, pp. 1–11, 2024, doi: 10.1016/j.scitotenv.2024.170610.
- [76] A. Bridhikitti *et al.*, “Sources and magnitude of heavy metals in sugarcane plantation soils with different agricultural practices and their implications on Sustainable waste-to-foods strategy in the sugar–ethanol industry,” *Sustain.*, vol. 15, no. 20, pp. 1–19, 2023, doi: 10.3390/su152014816.
- [77] D. L. F. Caetano, E. F. de Oliveira, and C. H. Zawadzki, “Drivers of fish diversity in Neotropical streams of the Upper Paraná River: The role of mesohabitats, riparian structure, and regional factors,” *Aquat. Sci.*, vol. 87, no. 4, pp. 98–115, Oct. 2025, doi: 10.1007/s00027-025-01225-8.
- [78] R. Turyahabwe, C. Mulinya, and W. A. Shivoga, “Relationships between land use, habitat quality, physicochemical water quality and fish communities in the Sironko River Catchment, a mountainous tropical stream flowing into the Lake Kyoga in Eastern Uganda,” *Lakes Reserv. Sci. Policy Manag. Sustain. Use*, vol. 27, no. 2, pp. 1–14, 2022, doi: 10.1111/lre.12406.
- [79] G. Rashid, R. Singh, A. Kumar, and P. Paramasivam, “Spatiotemporal variation in fish species distribution and abundance in the Vaishav stream, Kashmir Himalaya-India,” *PLoS One*, vol. 20, no. 2 February, pp. 1–27, 2025, doi: 10.1371/journal.pone.0316280.
- [80] H. Ayub, U. Ijaz, M. Arshad, F. Latif, S. S. Habib, and A. Al-Eman, “Influence of seasonal and spatial variations in physico-chemical parameters and plankton and macrophyte abundance on the diet composition of *Labeo gonius* in Chashma Lake, Indus River,” *Environ. Monit. Assess.*, vol. 197, no. 9, p. 1048, Aug. 2025, doi: 10.1007/s10661-025-14519-z.
- [81] T. M. Detmer *et al.*, “Community-wide transient dynamics of lake fish populations in response to two decades of suppressing an introduced predator,” *J. Appl. Ecol.*, vol. 62, no. 6, pp. 1406–1420, 2025, doi: 10.1111/1365-2664.70064.
- [82] S. Donadi *et al.*, “Reduced predation and competition from herring may have contributed to the increase of three-spined stickleback in the Baltic Sea,” *ICES J. Mar. Sci.*, vol. 82, no. 2, pp. 1–19, Feb. 2025, doi: 10.1093/icesjms/fsae168.
- [83] S. M. Thomaz, A. L. P. Cardozo, B. A. Quirino, K. Y. Yofukuji, M. H. F. Aleixo, and R. Fugi, “A review of the ecological role of aquatic macrophytes on freshwater fish,” *Hydrobiologia*, vol. 852, no. 13, pp. 3257–3290, Jul. 2025, doi: 10.1007/s10750-025-05819-z.
- [84] J. Dickson *et al.*, “A review of the historic and present ecological role of aquatic and shoreline wood, from forest to deep sea,” *Biol. Rev.*, vol. 101, pp. 1091–1119, 2025, doi: 10.1002/brv.70117.
- [85] H. Xi, T. Li, Y. Yuan, Q. Chen, and Z. Wen, “River ecosystem health assessment based on fuzzy logic and harmony degree evaluation in a human-dominated river basin,” *Ecosyst. Heal. Sustain.*, vol. 9, pp. 1–12, 2023, doi: 10.34133/ehs.0041.
- [86] G. Hou *et al.*, “Dominant species play a leading role in shaping community stability in the northern Tibetan grasslands,” *J. Plant Ecol.*, vol. 16, no. 3, pp. 1–12, 2023, doi: 10.1093/jpe/rtac110.
- [87] J. Ge *et al.*, “Seasonal variations in macrobenthos communities and their relationship with environmental factors in the alpine yuqu river,” *Biology (Basel)*, vol. 14, no. 2, pp. 1–25, 2025, doi: 10.3390/biology14020120.
- [88] N. J. Waltham and M. Sheaves, “Hydrological connectivity and habitat condition shape fish assemblages on a tropical agricultural floodplain,” *ICES J. Mar. Sci.*, vol. 83, no. 2, Jan. 2026, doi: 10.1093/icesjms/fsag008.
- [89] K. N. Lin, Y. C. Lim, C. W. Chen, C. F. Chen, C. M. Kao, and C. Di Dong, “Spatiotemporal variation and ecological risk assessment of heavy metals in industrialized urban river sediments: Fengshan river in southern Taiwan as a case study,” *Appl. Sci.*, vol. 12, no. 3, pp. 1–15, 2022, doi: 10.3390/app12031013.
- [90] M. B. Hossain *et al.*, “Contamination status and associated ecological risk assessment of heavy metals in different wetland sediments from an urbanized estuarine ecosystem,” *Mar. Pollut. Bull.*, vol. 185, pp. 1–9, 2022, doi: 10.1016/j.marpolbul.2022.114246.