



Influence of water quality and habitat characteristics on fish assemblages in two river systems of Northern Mindanao, Philippines

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ABSTRACT: This study assessed fish assemblages and their relationships with environmental variables in the Initao and Gimangpang Rivers of northern Mindanao, Philippines, to inform evidence-based river management. A total of 409 individuals representing five families and at least nine native species were documented, with Gobiidae and Eleotridae dominating both systems. The Initao River recorded slightly higher abundance ($n = 213$) than the Gimangpang River ($n = 196$). Mean fish relative density differed significantly among riverine reaches ($F = 11.12$; $p < 0.02$), increasing from upstream to downstream, although assemblage structure between rivers was not significantly different ($F = 1.22$; $p > 0.05$). Species dominance varied, with *Channa macrocephalus* prevalent in Initao (21.60%) and *Sicyopterus lagocephalus* in Gimangpang (23.98%). Water quality parameters (DO, BOD, nitrate, phosphate, temperature, pH) were within recommended limits for aquatic life, indicating generally suitable habitat conditions. PCA (49.16% explained variance) identified substrate type, riparian vegetation, depth, landscape cover, and water quality as key drivers of assemblage patterns. Practically, these findings highlight the importance of protecting riparian vegetation, regulating land use, and maintaining water quality to sustain native fish populations. Fish collection was conducted under appropriate local authorization and followed environmental ethics protocols, including minimal handling stress, selective sampling, and immediate release of non-retained specimens to reduce ecological disturbance.

Keywords: fish community; freshwater ecology; multivariate analysis; freshwater systems; tropical water quality.

Influência da qualidade da água e das características do habitat nas assembleias de peixes em dois sistemas fluviais no Norte de Mindanao, Filipinas

RESUMO. Este estudo avaliou as assembleias de peixes e suas relações com variáveis ambientais nos rios Initao e Gimangpang, no norte de Mindanao, Filipinas, com o objetivo de fornecer subsídios para a gestão de rios baseada em evidências. Foram documentados 409 indivíduos representando cinco famílias e pelo menos nove espécies nativas, com Gobiidae e Eleotridae dominando ambos os sistemas. O rio Initao apresentou uma abundância ligeiramente maior ($n = 213$) do que o rio Gimangpang ($n = 196$). A densidade relativa média de peixes diferiu significativamente entre os trechos do rio ($F = 11,12$; $p < 0,02$), aumentando do trecho superior para o inferior, embora a estrutura das assembleias entre rios não tenha diferido significativamente ($F = 1,22$; $p > 0,05$). A dominância de espécies variou, com *Channa macrocephalus* predominando em Initao (21,60%) e *Sicyopterus lagocephalus* em Gimangpang (23,98%). Os parâmetros de qualidade da água (OD, DBO, nitrato, fosfato, temperatura, pH) estavam dentro dos limites recomendados para a vida aquática, indicando condições de habitat geralmente adequadas. A Análise de Componentes Principais (PCA) (49,16% da variância explicada) identificou o tipo de substrato, vegetação ripária, profundidade, cobertura da paisagem e qualidade da água como fatores-chave que determinam os padrões das assembleias. Na prática, estes achados destacam a importância de proteger a vegetação ripária, regular o uso do solo e manter a qualidade da água para sustentar populações nativas de peixes. A coleta de peixes foi realizada sob autorização local adequada e seguindo protocolos éticos ambientais, incluindo manuseio mínimo, amostragem seletiva e liberação imediata de espécimes não retidos, para reduzir os distúrbios ecológicos.

Palavras-chave: comunidade de peixes; ecologia de água doce; análise multivariada; sistemas de água doce; qualidade da água tropical.

1. INTRODUCTION

Freshwater ecosystems represent some of the most biologically diverse yet vulnerable habitats on the planet.

Globally, rivers and streams harbor significant levels of biodiversity but are increasingly threatened by anthropogenic pressures, including land use change, habitat

modification, pollution, and overexploitation (VÖRÖSMARTY et al., 2010; MA et al., 2025). In the Philippines, the inland waters are particularly critical, given the country's status as a megadiverse nation and a recognized hotspot of freshwater endemism (CABRIDO, 2016). With 211 lakes, 18 major rivers, and 22 marshlands, the archipelago supports a wide range of fish taxa, many of which are endemic and highly sensitive to environmental disturbance (HERRE, 1927; ROQUE et al., 2019).

Riverscapes and other lotic systems perform vital ecological functions by providing spawning, feeding, and migratory habitats for diverse fish assemblages (FEIO et al., 2023). The integrity and structure of these assemblages, however, are closely linked to environmental and habitat variables such as water quality, substrate composition, depth, and surrounding land use (JOHNSON et al., 2005; MIRANDA et al., 2022). Heterogeneous habitats tend to support more diverse and stable fish communities, while habitat alterations, often resulting from deforestation, agricultural expansion, or urbanization, can disrupt ecological niches and negatively affect native species (MONIRUZZAMAN et al., 2021). Consequently, fish assemblages are widely regarded as reliable bioindicators of freshwater ecosystem health (Karr, 1981), making them valuable subjects for ecological monitoring and conservation assessments.

In Northern Mindanao, the Mt. Kitanglay is locally recognized as an important ecological frontier, hosting terrestrial and aquatic biodiversity. Despite this, limited research has been conducted on its river systems, particularly in relation to ichthyofaunal assemblages and the environmental variables shaping their structure. Existing studies on Philippine gobioid and riverine fishes have largely focused on Luzon (CORPUZ et al., 2015; ROQUE et al., 2019), leaving Mindanao's freshwater biodiversity relatively underexplored. This lack of ecological data presents challenges for the development of science-based conservation strategies in the region, especially since riverine systems in Northern Mindanao are increasingly subjected to pressures from agricultural run-off, quarrying, and expanding human settlements.

Investigating the influence of environmental and habitat variables on fish assemblages in the river systems of Mt. Kitanglay is therefore timely and necessary. Such research will not only contribute to filling significant knowledge gaps in freshwater fish ecology in Mindanao but will also provide critical insights for biodiversity conservation, resource management, and community-based protection efforts in the region. By identifying the key environmental predictors structuring fish communities, this study can guide conservation practitioners and local government units in prioritizing species and habitats that are most at risk, thereby contributing to the sustainable management of freshwater ecosystems in Northern Mindanao.

2. MATERIAL AND METHODS

2.1. Study sites and fish collections

Fish specimens were collected from two riverine sites in Misamis Oriental, Philippines, between January and April 2024. Site 1 was the Initao River, a lotic system draining from the foothills of the Mt. Kitanglay and flowing through the Initao–Libertad Protected Landscape and Seascape. Site 2 was the Gimangpang River, a tributary within the

same watershed that traverses lowland agricultural and residential areas before merging with downstream channels. Both sites are characterized by riparian vegetation consisting of mixed native and cultivated plant species.

Prior to field sampling, an entry protocol and reconnaissance survey were conducted in coordination with the Barangay Councils, the city government office, and selected local residents. These activities were undertaken to present the objectives of the study, secure formal permission to conduct fieldwork, and ensure community cooperation in facilitating access to sites and relevant information.

A total of nine sampling stations were established along the longitudinal profile of each river, with three stations each in the upstream, midstream, and downstream sections. Each station covered approximately 100 m of river length and was selected to represent the range of discrete habitat types present. Fish sampling was carried out during the daytime using a combination of seine nets, hand nets, and cast nets in deeper sections. At each station, sampling lasted approximately 60 minutes. Captured individuals were counted and identified to the lowest possible taxonomic level using FishBase as a primary reference (FROESE & PAULY, 2023). Native, endemic, juvenile, and gravid individuals were released after *in situ* identification, while representative specimens were preserved in 10% buffered formaldehyde for further documentation and verification in the laboratory.

All fish specimens captured were handled in accordance with established animal care and fisheries research ethical guidelines (e.g., IACUC-approved protocols and American Fisheries Society standards). Captured individuals were processed using minimal-stress handling techniques, including the use of wet hands or soft mesh nets, reduced air exposure (<30 seconds), and temporary holding in aerated containers. Native, endemic, juvenile, and gravid individuals were identified *in situ* and immediately released at their point of capture to minimize disturbance and post-release mortality. Representative voucher specimens were humanely euthanized using an approved anesthetic overdose (e.g., MS-222 at recommended concentrations), fixed in 10% buffered formaldehyde for 24–48 hours, and subsequently transferred to 70% ethanol for long-term preservation, documentation, and taxonomic verification.

2.2. Environmental and habitat variables

Water samples were collected in triplicate from nine sampling stations along each studied river. Samples were aseptically obtained from the mid-surface of the water column using sterile polyethylene containers. Primary water quality parameters measured included biological oxygen demand (BOD, mg L⁻¹), dissolved oxygen (DO, mg L⁻¹), nitrate as NO₃-N (mg L⁻¹), pH, phosphate (mg L⁻¹), temperature (°C), and total suspended solids (TSS, mg L⁻¹). Measurements of DO, temperature, and pH were conducted *in situ* using a portable hand-held device, while all other parameters were analyzed in the laboratory. Geographic coordinates and elevation were recorded at each sampling station using a GPS device. At three points within each station, stream depth, water velocity, and substrate composition were determined. Mean depth (cm) was measured using a weighted calibrated string, and stream flow velocity (m s⁻¹) was estimated with a simple float method. Substrate composition was categorized into

organic detritus, silt, mud, sand (0.02-2 mm), gravel (2-64 mm), cobble (64-256 mm), and boulder (>256 mm) following MAY and BROWN (2000). Vegetation cover (%) was visually estimated based on the relative abundance of macrophytes within the sampling transect and along both riverbanks. Adjacent land use was classified according to riparian and watershed characteristics: urban (1.5), agricultural (1.0), grassland (0.5), and forested areas (0.0) (CORPUZ et al., 2015).

2.3. Statistical analysis

Fish abundance, expressed as the number of individuals surveyed, and relative abundances were quantified per river system. Cumulative fish abundance data satisfied normality assumptions (Shapiro-Wilk test, $p < 0.05$); therefore, a one-way ANOVA was used to test for significant differences in mean pooled densities among and between the two rivers and their respective stream sections ($p < 0.05$). Abundance data were $\log_{10}(x+1)$ transformed before analysis to normalize distributions. Descriptive statistics of environmental variables were also computed. To reduce redundancy, Spearman's rank-order correlation coefficients (r_s) were calculated among environmental variables (SU et al., 2021).

Indirect gradient analysis using principal component analysis (PCA) was performed to examine variability among riverine sections and to identify the dominant gradients of species turnover, expressed as standard deviation (SD) units of beta diversity and to evaluate species–environment relationships and to identify environmental variables most

strongly associated with species distributions (TER BRAAK; VERDONSCHOT, 1995; LEGENDRE; LEGENDRE, 1998). The significance of CCA models was tested via Monte Carlo permutations (999 runs, $p < 0.05$).

Community similarity among river sections and across rivers was assessed using the Bray–Curtis similarity index (CLARKE, 1993) to classify riverine groups according to log-transformed abundance data. All statistical analyses were performed using Paleontological Statistics software, version 4.03 (HAMMER et al., 2001).

3. RESULTS

3.1. Fish composition and abundance

Fish survey collected a total of 409 fish individuals belonging to 5 families, mainly dominated by Family Gobiidae, followed by Family Eleotridae, Channidae, Clariidae and Cyprinidae. This has a total of at least 9 native fish species in these two river systems (Table 1). The Initao River had the highest fish abundance ($n=213$) and the Gimangpang River ($n=196$). Mean fish relative density was statistically different across riverine reaches ($F=11.12$; $p < 0.02$), with increasing fish abundance from upstream to downstream. Fish collected per river system, however, did not exhibit significant variation ($F=1.22$; $p > 0.05$). As per fish species recorded, the dominant fish species were *C. macrocephalus* (21.60%) at the Initao River and *S. lagocephalus* (23.98%) at the Gimangpang River, respectively. The least species were *G. celebius* (5.63%) at the Initao River and *Barbodes* sp. (3.06%) at the Gimangpang River, respectively.

Table 1. Abundance (A) and relative abundance (RA) of freshwater fishes inhabiting the river systems traversing Mt. Kitanglay, Initao, Misamis Oriental, captured from January to April 2024.

Tabela 1. Abundância (A) e abundância relativa (AR) de peixes de água doce que habitam os sistemas fluviais que atravessam o Monte Kitanglay, em Initao, Misamis Oriental, capturados de janeiro a abril de 2024.

Family	Species name	Endemism	Initao River		Gimangpang River	
			A	RA (%)	A	RA (%)
Gobiidae	<i>Awaous melanocephalus</i>	Native	14	6.57	26	13.27
Gobiidae	<i>Awaous ocellaris</i>	Native	25	11.74	16	8.16
Eleotridae	<i>Giuris margaritacea</i>	Native	28	13.15	19	9.69
Gobiidae	<i>Glossogobius celebius</i>	Native	12	5.63	8	4.08
Channidae	<i>Channa striata</i>	Native	16	7.51	21	10.71
Clariidae	<i>Clarias macrocephalus</i>	Native	46	21.60	25	12.76
Gobiidae	<i>Periophthalmus barbarus</i>	Native	13	6.10	28	14.29
Cyprinidae	<i>Barbodes</i> sp.	Native	21	9.86	6	3.06
Gobiidae	<i>Sicyopterus lagocephalus</i>	Native	38	17.84	47	23.98
Total			213		196	

3.2. Water quality and habitat characteristics

The mean (\pm SD) values of the physicochemical parameters of water from the two rivers are summarized in Table 2. Minimal spatial variation in biological oxygen demand (BOD) was observed, with upstream stations exhibiting the lowest mean concentrations, while downstream portions are still within the limits of organic pollution (MOREIRA et al., 2025). Dissolved oxygen (DO) concentrations were comparatively reduced in midstream to downstream reaches; however, they were consistently still within the recommended threshold of 5 mg L⁻¹ for aquatic life support. Nitrate (NO₃-N) and phosphate concentrations were within the prescribed limits of 7.0 mg L⁻¹ and 0.5 mg L⁻¹, respectively. Similarly, pH (6.5–9.0) and temperature (26–31 °C) values were within the acceptable ranges. Total suspended solids (TSS) concentrations did

not surpass the Class C standard of 80 mg L⁻¹ (DENR, 2015).

The two river systems had mostly muddy-sandy substrates, especially in the downstream portions. Water velocity ranged from 0.3 to 0.9 m/s, with a mean water depth of 0.2-0.7 m. Mostly, the river systems were grassland and agricultural land with few human settlements near the riverbanks.

3.3. Multivariate analyses on fish abundance

Twelve environmental variables, including water quality and habitat characteristics, were analyzed using Principal Component Analysis (PCA; Table 3). The PCA produced two axes explaining 41.89% of the variation in fish assemblages (Figure 1). Fish species most closely linked to river conditions influenced the distribution of sites and

species along the first axis. Upstream sites were clearly separated from other sections on PC1 and more distinct on PC2, while midstream sites overlapped, and downstream sites showed similar patterns. The second axis (28.16% variance; eigenvalue = 0.41) reflected further gradients in

assemblage composition due to environmental differences. The maximum gradient length exceeded 4 SD units, with no species shared between the extremes, supporting the use of a unimodal response model for the dataset.

Table 2. Mean water quality of the river systems (upstream (U), midstream (M), and downstream (D)) traversing Mt. Kitanglay, Initao, Misamis Oriental, recorded from January to April 2024.

Tabela 2. Qualidade média da água dos sistemas fluviais (a montante (U), no curso médio (M) e a jusante (D)) que atravessam o Monte Kitanglay, em Initao, Misamis Oriental, registrada de janeiro a abril de 2024.

Water quality variables	Initao River			Gimangpang River			DENR Class C standards
	U	M	D	U	M	D	
BOD (mg L ⁻¹)	1.22±1.13	2.12±0.73	4.17±1.11	1.61±1.13	3.17±.77	3.22±1.18	≤ 5 mg/L
Dissolved oxygen (mg L ⁻¹)	6.87±0.86	6.77±1.06	5.57±2.16	7.51±1.16	6.23±0.87	6.09±0.16	≥ 5 mg/L
NO ₃ -N (mg L ⁻¹)	0.37±1.06	0.41±0.78	0.43±0.56	0.29±0.33	0.31±0.67	0.33±0.56	≤ 7.0 mg/L
pH	8.02	7.76	7.16	8.76	8.21	8.34	6.5–9.0
Phosphates (mg L ⁻¹)	0.01±1.01	0.01±0.32	0.02±0.89	0.01±0.34	0.01±0.98	0.01±0.22	≤ 0.5 mg/L
Temperature (°C)	26.17	27.23	27.87	27.17	28.21	28.11	~26–31 °C
Total Suspended Solids (mg L ⁻¹)	8±1.92	11±0.42	11±1.12	5±1.13	5±1.56	6±0.62	~100 mg/L

Table 3. Relative eigenvalues, percentage of variation, and weights of water quality and habitat variables of the first two principal components (PC) axes using log-transformed abundance data.

Tabela 3. Autovalores relativos, percentagens de variação e pesos das variáveis de qualidade da água e do habitat dos dois primeiros eixos dos componentes principais (CP), utilizando dados de abundância transformados em logaritmo.

	PC 1	PC 2
% variation	31.13	16.17
Eigenvalues	3.68	2.61
Nitrate	0.39	0.71
Phosphate	1.12	2.21
Total suspended solids	1.03	0.59
pH	0.16	0.58
Dissolved oxygen	0.09	0.55
Biological oxygen demand	2.32	2.45
Temperature	2.09	1.22
Depth	0.76	0.33
Substrate types		
Muddy	0.52	0.94
Sand	0.79	0.25
Landscape uses		
Grassland	1.51	0.31
Agriculture	0.57	0.75

3.4. Fish abundance and environmental characteristics

Fish assemblages did not differ significantly between the two rivers ($p > 0.05$). In PC1 (24.08% variance), the Initao River separated from the Gimangpang River, while in PC2 (25.52%), upstream sites were slightly distinct from mid- and downstream sites. PCA showed that site- and species-environment associations explained 49.16% of fish assemblage variability (eigenvalues: 0.306 and 0.212; Figure 2). The longitudinal gradient of the rivers largely drove variation in assemblages. Key factors influencing fish distribution included land use/cover, substrate type, and water quality parameters such as DO, BOD, depth, and riparian vegetation.

The lack of a significant difference in fish assemblages between the Initao and Gimangpang Rivers ($p > 0.05$) indicates that overall ecological conditions and disturbance levels are similar in both systems. However, multivariate analysis revealed patterns not seen in simpler comparisons. In PC1 (24.08% variation), Initao separated from

Gimangpang, likely due to differences in habitat quality and land use. In comparison, PC2 (25.52% variation) showed upstream sites partially distinct from mid- and downstream sites, reflecting the influence of longitudinal gradients on fish communities. This aligns with the River Continuum Concept, where biological changes occur along streams, though human activities can modify these patterns (FEIO et al., 2023; WANG et al., 2024).

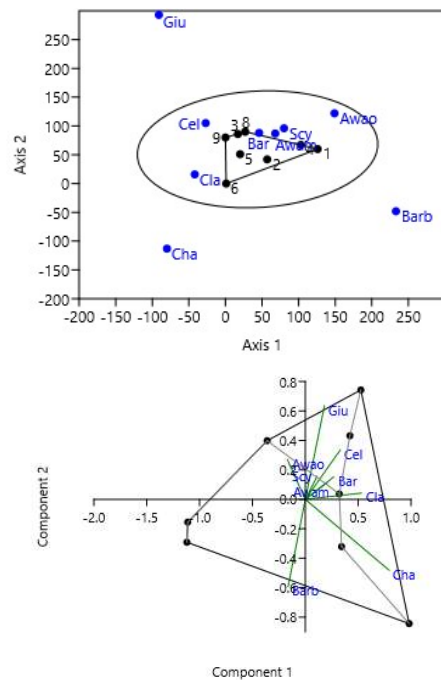


Figure 1. Plot of scores of the first two axes from the PCA analysis for fish assemblages in the river systems of Mt.Kitanglay, Initao, Misamis Oriental.

Figura 1. Gráfico dos escores dos dois primeiros eixos da análise de componentes principais (PCA) das assembleias de peixes nos sistemas fluviais do Monte Kitanglay, em Initao, Misamis Oriental.

3.5. Similarity

The mean similarity among river sections was 69.83% (Table 4). Upstream and downstream sites were less similar, showing no more than 50% similarity (11.11 ± 2.18 ; 0.640–

0.703), a pattern also seen across both rivers. This moderate variation aligns with the ordination analyses, indicating that fish assemblages along the rivers are generally homogeneous due to similar environmental conditions and landscape coverage.

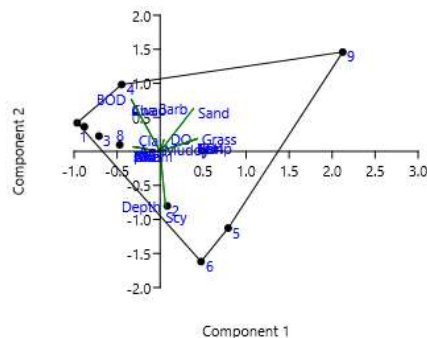


Figure 2. Plot of scores of the first two axes from the PCA analysis for fish assemblages, water quality, and habitat characteristics in the river systems of Mt.Kitanglay, Initao, Misamis Oriental.

Figura 2. Gráfico dos escores dos dois primeiros eixos da análise PCA para assembléias de peixes, qualidade da água e características do habitat nos sistemas fluviais do Monte Kitanglay, em Initao, Misamis Oriental.

4. DISCUSSION

Likewise, some studies conformed similar observations in this study, such that, for instance, coastal and riverine systems in China consistently report Gobiidae as dominant taxa, closely linked to hydrographic conditions and habitat structure. The observed increase in abundance from upstream to downstream also follows longitudinal patterns commonly described in international rivers. In subtropical Chinese rivers, fish assemblages vary significantly along headwater-to-downstream gradients due to changes in habitat complexity and substrate composition, while other studies identify altitude and substrate type as primary drivers shaping spatial distribution (ANTONIAZZI et al., 2023; MA et al., 2025).

High species standard deviation along the principal component axis indicates elevated beta diversity and strong species turnover across longitudinal river gradients. Despite this, assemblage composition remained broadly similar between rivers and particularly between upstream and mid-downstream reaches, suggesting that hydro-geographical connectivity and shared catchment characteristics promote dispersal and recolonization among adjacent systems. Comparable patterns have been documented in tropical rivers where connectivity and environmental gradients jointly structure fish communities (FEIO et al., 2023; WANG et al., 2024).

Table 4. Bray-Curtis similarity (%) between the river systems of Mt.Kitanglay, Initao, Misamis Oriental, based on fish species and abundance data.

Tabela 4. Similaridade de Bray-Curtis (%) entre os sistemas fluviais do Monte Kitanglay, Initao, Misamis Oriental, com base em dados de espécies e de abundância de peixes.

		Initao River			Gimangpang River		
		US	MS	DS	US	MS	DS
Initao River	US	1.000	0.741	0.759	0.667	0.909	0.703
	MS	0.741	1.000	0.932	0.656	0.821	0.732
	DS	0.759	0.932	1.000	0.697	0.833	0.797
Gimangpang River	US	0.667	0.656	0.597	1.000	0.702	0.640
	MS	0.909	0.821	0.833	0.702	1.000	0.685
	DS	0.703	0.732	0.797	0.440	0.685	1.000

Note: US-Upstream, MS-Midstream, DS-Downstream.

Nota: US - nascentes, MS - meio, DS - foz.

Partial differentiation of upstream assemblages likely reflects dispersal limitation and habitat filtering, as many headwater taxa exhibit small body size, benthic habits, and short larval drift phases that restrict movement across steep gradients and barriers (CORPUZ et al., 2023; KHAING et al., 2024). The dominance of gobiid assemblages across both rivers further supports this interpretation, consistent with amphidromous species maintaining regional connectivity while tracking stable substrates and flow conditions (BIRK et al., 2022). The concordance between DCA and direct gradient analyses confirms that environmental gradients, rather than stochastic processes, primarily structured assemblage distribution across sites (Figure 1).

Environmental variables explained 49.16% of fish assemblage variation, with land cover, substrate type, depth, riparian vegetation, and water quality (DO, BOD) being the most important. Substrate diversity creates more habitats, riparian vegetation regulates temperature and nutrients, and water quality filters species, especially in tropical rivers where oxygen and organic pollution strongly

affect communities (BIRK et al., 2022; KHAING et al., 2024; MOREIRA et al., 2025).

Similar patterns have been reported in other tropical rivers, where longitudinal gradients create slight changes in fish communities while overall assemblage structure remains consistent (TERRA et al., 2010; SU et al., 2021). Stream depth, substrate type, riparian vegetation, and water quality act as environmental filters that shape species distribution and abundance (VANNOOTE et al., 1980; POFF, 1997). The overall similarity of fish assemblages highlights the influence of broad-scale habitat and catchment factors, while small differences between upstream and downstream sites emphasize the role of local habitat variation in structuring communities (WALTERS et al., 2003; TEJERINA-GARRO et al., 2005).

5. CONCLUSIONS AND RECOMMENDATIONS

The survey documented 409 fish individuals representing at least nine native species across two river systems, with assemblages dominated by Gobiidae and Eleotridae. While the Initao River exhibited higher fish

abundance than the Gimangpang River, overall assemblage composition did not differ significantly between systems.

Variability in fish assemblages was structured primarily along the longitudinal gradient, with upstream reaches showing slight differences from midstream and downstream sections.

Multivariate ordination analysis identified habitat characteristics, substratum type, land cover, and water quality parameters (particularly dissolved oxygen (DO), biological oxygen demand (BOD), depth, and riparian vegetation) as the principal drivers shaping assemblage structure.

Despite minor spatial dissimilarity, the relatively high similarity index (69.83%) indicated strong assemblage homogeneity across both rivers, reflecting comparable environmental conditions and shared catchment-level influences.

These findings underscore the importance of strengthening river governance through existing environmental policies and participatory management approaches. Protection and rehabilitation of riparian vegetation, maintenance of substratum heterogeneity, and sustained monitoring of key water quality parameters (e.g., DO, BOD, nutrients) should be integrated into local watershed management plans and aligned with national water quality standards.

Regulatory measures addressing agricultural runoff, riparian land conversion, and other anthropogenic pressures must be enforced in coordination with local government units (LGUs), community stakeholders, and relevant environmental agencies. Community-based river stewardship programs, participatory monitoring initiatives, and multi-sectoral watershed councils can enhance compliance, promote shared accountability, and support adaptive management.

Furthermore, conservation strategies should prioritize longitudinal connectivity from headwaters to downstream reaches to ensure habitat continuity and ecological resilience. Long-term and seasonal monitoring, embedded within local policy frameworks and co-management arrangements, is essential to inform evidence-based decision-making and sustainable river resource governance.

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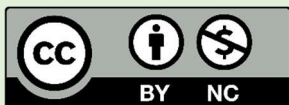
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