

# Environmental and habitat variables influencing the fish assemblages in the three tropical river systems in Bataan Peninsula, Luzon Island, Philippines

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**Abstract.** Three poorly-studied river systems (Almacen, Bagac, and Talisay) of Bataan, Central Luzon, Philippines were assessed to evaluate the key environmental and habitat variables influencing the fish assemblages. The study collected a total of 1747 fish specimens belonging to at least 52 species. Gobiids comprised the highest number of fish species ( $n=6$ ). The exotic cichlids (mainly *Sarotherodon melanotheron* and *Oreochromis niloticus*) comprised 80.66% of the total fish abundance. Log<sub>10</sub>-transformed abundance data were used in indirect (detrended correspondence analysis, DCA), and direct (canonical correspondence analysis, CCA) gradient ordination analysis. The DCA explained the 44.53% variation in fish assemblages as a response to river longitudinal gradient change. Heterogeneity of fish species and fish densities along the riverine stream sections (upstream, midstream, and downstream) was observed. From the 23 environmental and habitat variables, CCA (61.53% variability on the first and second ordination axes) recognized depth, substratum types (clay bottom type), and landscape use (forested areas) as the most weighted causative parameters structuring the fish assemblages (within and between stream variations). Bray-Curtis similarity index using species and abundance data divulged a low mean similarity of 29.43% among the three rivers, confirming the high beta diversity estimated in indirect ordination analysis. The present study also updated the water quality parameters and the fish communities inventoried in the three river systems.

**Key Words:** Balanga, conservation, ecology, landscape use, ordination analysis.

**Introduction.** Philippines is known to be an important area of high endemism for freshwater biomes, due to its unique distribution of fish species within the 211 lakes, 18 major rivers, and 22 marshlands (Cabrido 2016). Among the freshwater habitats, riverscapes and other lotic systems sustain vital functions in the growth, survival, and migratory behavior of fish assemblages with capability to adapt in gradient changes in riverine profile (Humpl & Pivnicka 2006; Paller et al 2013). Like most developing countries, river systems play a crucial role in supporting local subsistence fisheries (Corpuz & Espaldon 2023), which are vital for local economic growth, particularly in rural communities (Tolentino et al 2022).

The integrity of fluvial fish assemblages as key bioindicators (Karr 1981) is significantly influenced by various environmental and anthropogenic factors (Angermeier & Davideanu 2004), and by the extent of conservation measures employed to the river systems (Roth et al 1996; Johnson et al 2005; Rodrigues-Olarte et al 2006). The heterogeneity of habitat types contributes to the complexity of the aquatic environment, supporting various niches that are crucial for fish survival and reproduction (Moniruzzaman et al 2021). Habitat alteration as the result of human activities may pose a significant change in the river sub-habitats, which in turn, may impact the native fish communities (Paller et al 2011). Several studies have been conducted to quantify the

influence of environmental and habitat variables on fish assemblage, highlighting the complex interplay between ecological factors and fish community structures (Herder & Freyhof 2006; Tunesi et al 2006; Corpuz et al 2015; Roque et al 2019). Understanding the environmental and habitat variables affecting fish populations is critical for the formulation of effective conservation strategies (Humpl & Pivnicka 2006). By systematically monitoring the key ecological parameters and the predictors of habitat change, conservationists can identify stressors affecting fish habitats, enabling them to prioritize areas and species in need of immediate intervention (Sanon et al 2020).

Quantitative community ecology studies play a crucial role in understanding the dynamics and health of ecological systems, yet their application to riverine fish assemblages in Central Luzon, Philippines, remains markedly underexplored. Moreover, few ecological studies have been done for fish assemblages due to the deficiency in current conservation status and data on fish taxa thriving in part of the Luzon Island (Roque et al 2019, 2022; Corpuz et al 2024).

The present study evaluated the influence of different environmental and habitat factors on ichthyofaunal assemblages from the three riverine ecosystems in Bataan, Philippines. Using indirect and direct ordination analyses, the study analyzed the contribution of water quality variables, substrate types and land use in structuring the fish assemblages along the longitudinal gradient profile of the three studied river systems.

## Material and Method

**Study sites.** The fish specimens were collected directly in the three main rivers of Bataan, Philippines. Talisay River (14°48'46"N; 120°33'19"E, at the river mouth) is the largest river systems of Bataan, Philippines. The main water source is coming from headwaters of Liyang Pilar and run 13 km before emptying into Manila Bay. The Bagac River (14°35'27"N; 120°23'22"E, at the river mouth) is situated in the northwestern portion of Mount Mariveles (South of Bataan) and is water-fed by the springs and run-offs from highlands before draining to the West Philippine Sea. The Almacen River (14°41'33"N; 120°33'53"E, at the river mouth) is one of the major river systems located in the northeast portion of Bataan, which provides navigational routes, irrigation, and a source of fishery resources to local communities. Almacen runs about 13 km from the mountain sources (Natib and Malasimbo) before emptying in Manila Bay. Apart from human settlements and commercial establishments, the river is impacted by multiple land use and habitat alterations in its catchment area, with a high incidence of environmental modifications in the medium and lower parts of the river basin. In the estuarine region of Almacen, the streams pass through aquaculture areas (brackishwater fishponds) with low concentrations of secondary mangrove forest. Fish specimens were collected from December 2021 to November 2022.

**Fish collection.** A total of nine sampling stations in the longitudinal profile of each studied river were selected. Three sampling stations were surveyed for every stream section (upstream, midstream, and downstream), covering about 100 m in each station and were sampled to cover the relative availability of discrete habitat types in every river section. Fish were collected using a 12V device for electrofishing, which was interchangeably operated by three persons. Seine net, hand-nets, and cast nets were also used in the deeper part of the river. Individual sampling run per station lasted about 60 min and was done during day time. Captured fish individual were counted and identified at lowest possible taxon using FishBase as an identification tool (Froese & Pauly 2023). Juvenile and gravid fishes and fishes that were classified as native or endemic were released after *in situ* identification. Representative individuals were preserved in 10% buffered formaldehyde solution for further documentation and identification in the laboratory.

**Environmental and habitat variables.** The water samples were collected in triplicates from the nine different sampling stations of each studied river. Samples were aseptically obtained from the mid-surface part of the water column using sterile polyethylene

containers. Primary water quality parameters including biological oxygen demand (BOD, mg L<sup>-1</sup>), chloride (mg L<sup>-1</sup>), color (TCU), dissolved oxygen (DO, mg L<sup>-1</sup>), fecal coliform (MPN 100 mL<sup>-1</sup>), nitrate as NO<sub>3</sub>-N (mg L<sup>-1</sup>), pH (range), phosphates (mg L<sup>-1</sup>), temperature (°C), total suspended solids (TSS, mg L<sup>-1</sup>) were determined. Excepting DO, temperature and pH, the parameters were determined in the laboratory. DO (mg L<sup>-1</sup>), temperature (°C) and pH levels were determined on-site using a hand-held device. Geographic position and elevation were also recorded for each sampling station using a global positioning system device. Depth, surface stream flow, and substrate were determined at three points within each sampling station. Mean depth (cm) was measured using a calibrated string with weights. Stream flow (m s<sup>-1</sup>) was measured using a simple float. Dominant substrate type was classified as organic detritus, silt, mud, sand (0.02–2 mm), gravel (2–64 mm), cobble (64–256 mm), and boulder (>256 mm) (May & Brown 2000). Vegetation cover (%) was estimated by the relative amount of macrophytes in the sampling path and the occupied areas in both sides of the riverbanks. Landscape use was categorized based on the characteristic of the riparian zone and adjacent river basin: urban (1.5), agricultural sites (1), grassland (0.5), and forested areas (0.0) (Corpuz et al 2015).

**Statistical analysis.** Fish densities (number of individuals collected in one species in 100 m<sup>2</sup>) and relative abundances were determined in each sampling station. Cumulative fish density data did follow the normality assumptions (Shapiro-Wilk test,  $p < 0.05$ ), and with that, ANOVA test was employed to determine the significant difference in mean values of pooled density among and between the three studied rivers and their stream sections ( $p < 0.05$ ). Abundance data were  $\log_{10}(x+1)$  transformed to linearize the relationship. Descriptive statistics of environmental variables were also computed.

Reduction analysis using Spearman's rank order correlation coefficients ( $r_s$ ) was initially performed to exclude the redundant variables (Humpl & Pivnicka 2006). Only the factors with  $r_s < 0.32$  ( $p < 0.05$ ) were retained in the analyses. Six environmental variables were eliminated including salinity, water velocity, pH, cobble-type substrate, muddy bottom, and number of settlements.

The indirect gradient analysis (detrended correspondence analysis, DCA) was employed to evaluate the stream section variability and described the most important gradient of species change. It also showed measure of beta diversity (standard deviation - SD units). The direct gradient analysis (canonical correspondence analysis, CCA) was used to evaluate and the sampling sites with environmental and habitat variables. These multivariate statistics also identified variables correlated maximally with species and sites data. Monte Carlo test with 999 random permutations was applied to test the significance ( $p < 0.05$ ) (Ter Braak & Verdonschot 1995; Legendre & Legendre 1998). Bray-Curtis Index (Clarke 1993) was used for multi-group comparison among river sections in each stream, and comparison of similar river sections between rivers. The unweight pair group method with arithmetic mean was used to classify the riverine groups according to species and  $\log_{10}$ -transformed abundance data. All statistical analyses were performed using Paleontological Statistic version 2.17 (Hammer et al 2001) and Statistica version 6.0.

## Results and Discussion

**Environmental data.** The summary (mean  $\pm$  SD) of the physicochemical properties of water from the three rivers is presented in Table 1. Spatial fluctuation of BOD levels was observed, with the upstream sites having the lowest mean BOD concentrations. The downstream section had moderately polluted waters (Wilhem 2009). The chloride levels did not exceed 50 mg L<sup>-1</sup> and were within the normal range (DAO 2016). The color of water as an indication of dissolved impurities was at the normal limit as specified by DAO (2016). The mean DO levels were comparatively low in midstream sites and constantly below the ideal 5 mg L<sup>-1</sup>. Except for the upstream of Almacen, the fecal coliform concentration in all sampling sites exceeded the standard limit of 200 MPN 100 mL<sup>-1</sup> for fishery water body classification (Class C) (DAO 2016). The levels of nitrate as NO<sub>3</sub>-N, and phosphate did not exceed the standard values (7.0 mg L<sup>-1</sup> for NO<sub>3</sub>-N and 0.5 mg L<sup>-1</sup>

for phosphate). The pH and water temperature readings were within the normal ranges (6.5–9.0 for pH and 26–31°C for temperature). The TDS in Almacen and the upstream sites of Talisay and Bagac did not surpass the ideal TDS value of 80 mg L<sup>-1</sup> for a Class C water body classification (DAO 2016), albeit the midstream and downstream sites of Talisay and Bagac exceeded the said water body classification guideline.

Table 1  
Water quality parameters (mean ± SD) in the stream sections of the studied river systems in Bataan, Philippines

Water quality variables	Talisay			Bagac			Almacen		
	D	M	U	D	M	U	D	M	U
Biological oxygen demand, mg L <sup>-1</sup>	13.67 ±1.73	8.33 ±0.58	2.67 ±0.58	8.33 ±1.73	6.16 ±1.15	1.75 ±0.58	7.67 ±5.13	7.33 ±3.33	2.72 ±1.08
Chloride, mg L <sup>-1</sup>	49.67 ±4.79	20.31 ±11.41	11.33 ±0.96	44.6 ±3.31	28.33 ±2.36	10 ±1.63	52.6 ±3.51	45 ±3.61	10.16 ±0.29
Color, TCU	5	5	5	5	5	5	1	5	5
Dissolved oxygen, mg L <sup>-1</sup>	5.57 ±0.06	3.17 ±0.92	4.96 ±0.4	4.93 ±0.29	3.73 ±0.91	4.63 ±0.51	5.41 ±1.09	4.48 ±0.94	6.19 ±1.33
Fecal coliform, MPN 100 mL <sup>-1</sup>	130670 ±34063	91670 ±577.35	2000 ±346.41	48000 ±2309	37670 ±2886.75	1670 ±262.99	853 ±782.65	1373.33 ±392.59	22.66 ±2.31
NO <sub>3</sub> -N, mg L <sup>-1</sup>	0.46 ±0.02	0.31 ±0.06	0.21 ±0.02	0.48 ±0.05	0.3 ±0.04	0.13 ±0.06	0.38 ±0.09	0.28 ±0.02	0.13 ±0.06
pH	7.43 ±0.12	7.24 ±0.15	7.3 ±0.26	7.17 ±0.12	7.03 ±0.15	7.4 ±0.34	7.25 ±0.21	7 ±0.19	7.5 ±0.18
Phosphates, mg L <sup>-1</sup>	0.13 ±0.03	0.10 ±0.001	0.05 ±0.01	0.1 ±0.001	0.07 ±0.03	0.01 ±0.001	0.13 ±0.06	0.05 ±0.01	0.14 ±0.07
Temperature °C	32.03 ±0.11	28.87 ±0.81	27.23 ±0.15	30.4 ±0.35	28.73 ±0.21	26.2 ±0.81	29.7 ±1.57	30.3 ±0.81	26.15 ±0.93
Total Suspended Solids, mg L <sup>-1</sup>	99 ±15.39	100 ±13.23	19 ±6.92	85 ±4.35	82.33 ±15.37	26.6 ±16.07	72 ±51.45	59.6 ±1.15	23.31 ±29.1

Note: D – downstream; M – midstream; U – upstream.

**Fish abundance and diversity.** Overall, the fish survey collected a total of 1747 fish individuals belonging to 32 families and at least 52 species (Table 2). Almacen had the highest fish abundance (n=770) followed by Bagac (n=505), and Talisay (n=472). Mean fish relative density was statistically different among riverine sections (F=21.44; p<0.01), with increasing fish densities in the sequence: upstream<midstream<downstream. Fish collected per sample area was 1.99 individuals per m<sup>2</sup> in the downstream sites, 1.02 individuals per m<sup>2</sup> in the midstream sites, and 0.28 individuals per m<sup>2</sup> in the upstream. No significant inter-river variation in fish density was observed (F=0.129; p>0.05); seasonal variation in pooled fish density was also not significant (F=0.339; p>0.05).

There were 42 fish species collected from Almacen, 29 from Bagac, and 28 from Talisay. Among the native fish species, gobiids comprised the highest number of species (n=6), whilst cichlids had the highest number of fish species (n=5) among the introduced fish species. In terms of relative abundance, tilapias (Cichlidae) 36.09%, and mullets (Mugilidae) 15.04% dominated the total fish individuals in Almacen, mostly collected from the downstream sites. The tilapias (Cichlidae) 33.96%, and ariid catfish (Ariidae) 28.09% dominated the total fish catch in Talisay, whilst tilapias (Cichlidae) 30.95%, ponyfishes or slipmouths (Leiognathidae) 9.92%, glassfishes (Ambassidae) 9.13%, and gobies (Gobiidae) 8.73% dominated the total fish individuals in Bagac (58% of the cumulative fish abundance). Overall, the family of cichlids comprised the bulk of the total fish abundance which predominantly consisted of black-chin tilapia, *Sarotherodon melanotheron* (52.56%), and the Nile tilapia, *Oreochromis niloticus* (28.10%).

Table 2

Fish assemblages (seriation of presence /absence) collected from the three studied rivers  
(Almacen, Bagac and Talisay), Bataan, Philippines

Families	Code	Fish Species	Origin of species	Position in water	Reproduction	Studied rivers		
						A	B	T
Ambassidae	Amb	<i>Ambassis miops</i>	N	W	egg			
Anabantidae	Ana	<i>Anabas testudineus</i>	N	B	egg			
Anguillidae	Ang	<i>Anguilla marmorata</i>	N	B	egg			
Apogonidae	Apo	<i>Apogon hyalosoma</i>	N	W	egg			
Ariidae	Ari	<i>Arius manillensis</i>	N	B	egg			
Carangidae	Car	<i>Carangoides hedlandensis</i>	N	W	egg			
Chanidae	Cha	<i>Chanos chanos</i>	N	W	egg			
Channidae	Chan	<i>Channa striata</i>	E	B	egg			
Cichlidae	Cic	<i>Oreochromis niloticus</i>	E	W	egg			
Cichlidae	Cic	<i>Oreochromis mossambicus</i>	E	W	egg			
Cichlidae	Cic	<i>Sarotherodon melanotheron</i>	E	W	egg			
Cichlidae	Cic	<i>O. niloticus x O. massambicus</i>	E	W	egg			
Cichlidae	Cic	<i>Mayaheros urophthalmus</i>	E	W	egg			
Clariidae	Cla	<i>Clarias batrachus</i>	N	B	egg			
Clariidae	Cla	<i>Clarias gariepinus</i>	E	B	egg			
Cynoglossidae	Cyn	<i>Cynoglossus bilineatus</i>	N	B	egg			
Cyprinidae	Cyp	<i>Cyprinus carpio</i>	E	W	egg			
Cyprinidae	Cyp	<i>Hypophthalmichthys nobilis</i>	E	W	egg			
Cyprinidae	Cyp	<i>Carassius auratus</i>	E	W	egg			
Eleotridae	Ele	<i>Butis butis</i>	N	W	egg			
Gerreidae	Ger	<i>Gerres sp.</i>	N	W	egg			
Gobiidae	Gob	<i>Glossogobius giuris</i>	N	B	egg			
Gobiidae	Gob	<i>Glossogobius aureus</i>	N	B	egg			
Gobiidae	Gob	<i>Rhinogobius sp.</i>	N	B	egg			
Gobiidae	Gob	<i>Platycephalus indicus</i>	N	B	egg			
Gobiidae	Gob	<i>Stiphodon sp.</i>	N	B	egg			
Gobiidae	Gob	<i>Sicyopus sp.</i>	N	B	egg			
Hemiramphidae	Hem	<i>Rhynchorhamphus georgii</i>	N	W	live-bearing			
Leiognathidae	Lei	<i>Leiognathus equulus</i>	N	W	egg			
Leiognathidae	Lei	<i>Gazza minuta</i>	N	W	egg			
Loricariidae	Lor	<i>Pterygoplichthys sp.</i>	E	B	egg			
Lutjanidae	Lut	<i>Lutjanus argentimaculatus</i>	N	W	egg			
Lutjanidae	Lut	<i>Lutjanus rivulatus</i>	N	W	egg			
Megalopidae	Meg	<i>Megalops cyprinoides</i>	N	W	egg			
Mugilidae	Mug	<i>Mugil sp.</i>	N	W	egg			
Muraenesocidae	Mur	<i>Gymnothorax sp.</i>	N	B	egg			
Osphronemidae	Osp	<i>Trichopodus pectoralis</i>	N	W	egg			
Osphronemidae	Osp	<i>Trichopodus trichopterus</i>	N	W	egg			
Pempheridae	Pem	<i>Pempheris sp.</i>	N	B	egg			
Poeciliidae	Poe	<i>Gambusia affinis</i>	E	W	live-bearing			
Poeciliidae	Poe	<i>Poecilia reticulata</i>	E	W	live-bearing			
Poeciliidae	Poe	<i>Poecilia sphenops</i>	E	W	live-bearing			
Polynemidae	Pol	<i>Eleutheronema tetradactylum</i>	N	W	egg			
Scatophagidae	Sca	<i>Scatophagus argus</i>	N	W	egg			
Sciaenidae	Sci	<i>Johnius borneensis</i>	N	W	egg			
Siganidae	Sig	<i>Siganus vermiculatus</i>	N	W	egg			
Sillaginidae	Sil	<i>Sillago sihama</i>	N	B	egg			
Synbranchidae	Syn	<i>Monopterus albus</i>	N	B	egg			
Terapontidae	Ter	<i>Leiopotherapon plumbeus</i>	N	B	egg			
Terapontidae	Ter	<i>Therapon jarbua</i>	N	B	egg			
Zenarchopteridae	Zen	<i>Zenarchopterus dispar</i>	N	W	live-bearing			
Zenarchopteridae	Zen	<i>Nomorhamphus sp.</i>	N	W	live-bearing			

Note: information on conservation status, position in water, trophic guilds, and reproduction are based on FishBase (Froese & Pauly 2023); A – Almacen; B – Bagac; T – Talisay; origin of species: N - native, E - exotic or non-native; position in water: B - benthic; W - water column.

**Multivariate analyses on fish assemblage.** Fourteen significant environmental variables were retained using PCA and were subjected to direct and indirect multivariate ordination analyses (Table 3). The DCA generated two axes that contributed to 44.53% (eigenvalue = 0.594) of the variability derived from the relative abundance of fish assemblage (Figure 1). The first DC axis explained the 25.57% variability in fish

assemblage as a function of river longitudinal gradient change (Figure 1A). The strong correlation between the most common fish species and those that are restricted in a particular river was discernable in the DCA plot. The fish species maximally correlated with the stream section caused the deviation of species and sampling site scores in the first ordination axis.

In the site plot, upstream sites clearly deviated from other stream sections at the DC1 axis, with a more apparent disjunction of Almacen from Talisay and Bagac at the DC2 axis. Midstream sites of the three studied rivers seemingly overlapped, whereas the downstream site scores of Talisay shared a conformity with the convex hull of Almacen site scores (Figure 1B). The second ordination axis (18.96%; eigenvalue = 0.129) also displayed a gradient of fish assemblage change and a deviation among river sections' scores caused by unknown environmental parameters. The maximum gradient length in either the first two ordination axes was >4.0 SD units. No species was shared at the opposite ends of the gradient. The findings satisfied the criteria to proceed to the unimodal response model (i.e., direct gradient CCA).

Table 3

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

	<i>PC 1</i>	<i>PC 2</i>
<i>% variation</i>	37.913	17.97
<i>Eigenvalues</i>	5.687	2.69
Coliform	<b>0.794</b>	0.206
Chloride	-0.156	0.116
Color	-0.008	-0.316
Nitrate as NO <sub>3</sub> -N	0.318	<b>0.737</b>
Total dissolved solids	<b>0.803</b>	0.005
pH	0.016	0.358
Dissolved oxygen	-0.069	0.595
Vegetation	<b>-0.884</b>	-0.065
Depth	<b>0.796</b>	0.323
<i>Substrate types</i>		
Clay	0.525	<b>0.694</b>
Sand	<b>0.769</b>	-0.205
<i>Landscape uses</i>		
Forest	<b>-0.929</b>	0.26
Grassland	0.571	<b>-0.731</b>
Agriculture	<b>0.757</b>	-0.575
Urban	<b>0.716</b>	0.499

Note: most significant weights of PC 1 and PC 2 are set in bold font; Jolliffe cut-off = 0.7, p<0.05.

The high species SD in DC axis indicates high beta diversity or high rate of species turnover from one assemblage to another along the stream gradients. It conforms to the very low similarity observed for species abundance and composition among the three rivers and most predominantly, between upstream vs. midstream-downstream sampling sites. The lack of hydro-geographical connectivity between stream sections can be one of the main causes of this significant spatial dissimilarity. Furthermore, the interaction of geographically separated populations is almost implausible considering that the studied rivers are separated by landmasses where their headwaters are originated in one elevation point. Barriers also influenced the interaction of upstream fish populations as the majority of these adaptive upstream fishes have weak dispersal strategies due to their innate attributes (viz), diminutive size (50–100 mm), poor swimmers, benthic dwellers, and short pelagic larval stages (Mejri et al 2012; Corpuz et al 2013).

Despite the proximity of the studied river systems, the inter-variability of fish assemblages was evident even for the upstream site scores. The notable divergence of

upstream sites scores from that of midstream and downstream can be attributed to the gobiid-rich feature of the upper river waters. This significant variability in fish assemblage structure along the longitudinal stream profile was also reported in other fish studies (Eros et al 2003; Tunesi et al 2006; Shervette et al 2007; Corpuz et al 2015). The DCA variances were in conformity with the direct ordination analysis as the position of species and sites scores of both plots were rather analogous to both analyses (Figures 1 and 2).

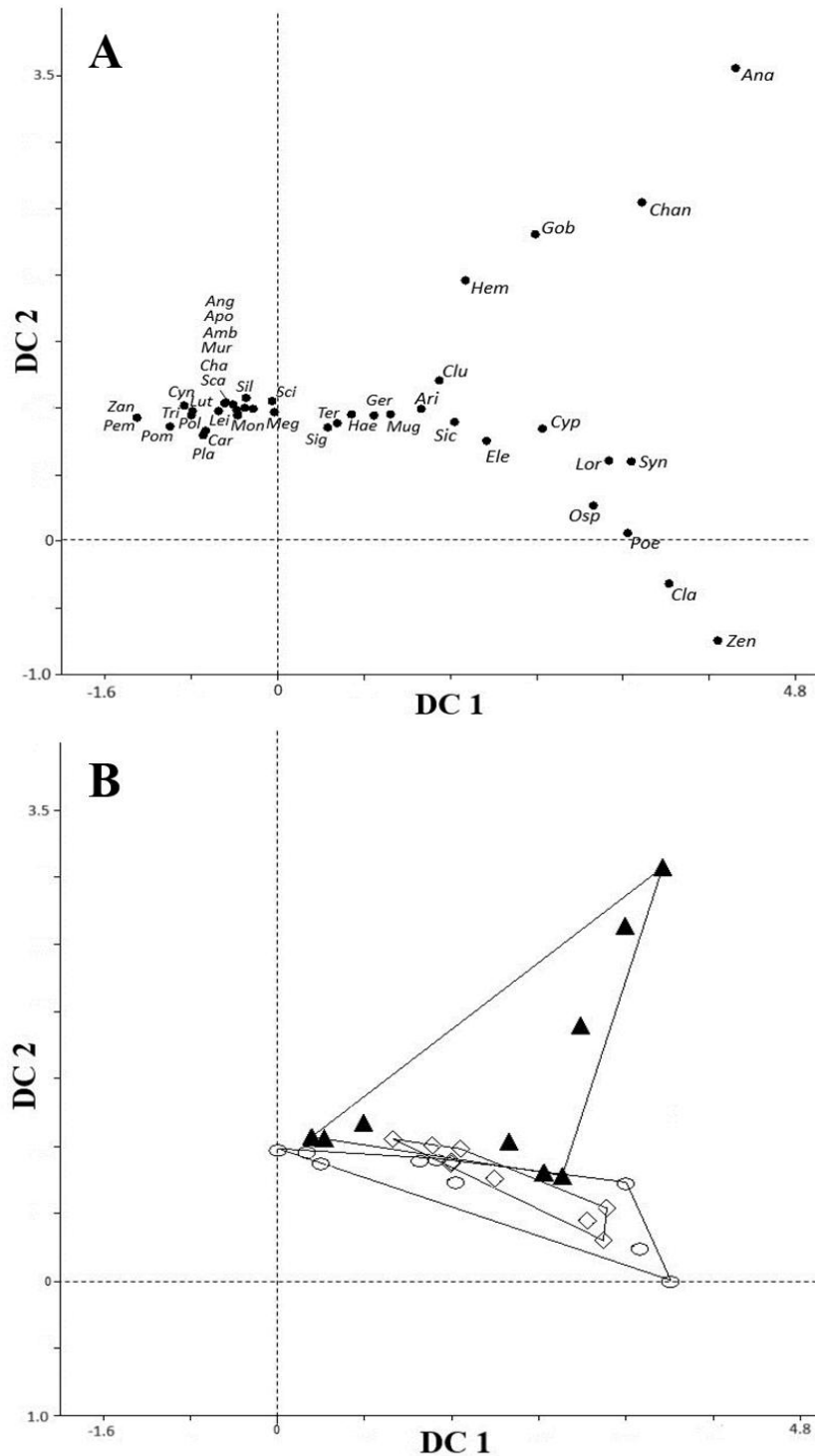


Figure 1. Plot of scores of the first two axes from the detrended correspondence (DC) analysis for fish species, and sampling river sites in Bataan, Philippines; A - species scores (see Table 2 for species codes); B - sampling site scores:  $\diamond$  Talisay,  $\circ$  Bagac,  $\blacktriangle$  Almacen; eigenvalues: DC 1 = 0.59, DC 2 = 0.29.

**Fish assemblage and environmental variables.** Fish assemblages were highly significantly different among the three streams ( $p < 0.01$ ). In CC1 (variation = 34.01%), downstream deviated from upstream and midstream sampling sites (Table 4). In CC2 (variation = 25.75%), upstream separated from the other studied sites (Figure 2). The site-environment and species-environment associations illustrated in the CCA had eigenvalues of 0.386 and 0.312, with 59.76% variability in fish assemblages on the first two axes (Table 4). The CCA ordination axis characterized the fish assemblage variability mainly caused by the longitudinal gradient profile in the stream sections of the studied river. The CCA recognized landscape use/land coverage, substratum type, and several environmental parameters as the most weighted causative variables influencing the fish assemblage. It is noteworthy to mention that the "forest" landscape use type is positively correlated with fish assemblages, indicating the importance of forested areas in maintaining the fish assemblage's integrity.

Table 4

Correlations of significant environmental variables of the first two CCA ordination axes

	CC 1	CC 2
<i>% Variation</i>	34.01	27.52
<i>Eigenvalues</i>	0.386	0.312
Coliform	-0.265	<b>-0.815</b>
Nitrate as NO <sub>3</sub> -N	-0.109	-0.160
Total Suspended Solids	-0.682	<b>-0.639</b>
Vegetation	0.608	<b>0.763</b>
Depth	<b>-0.826</b>	<b>-0.783</b>
<i>Substrates</i>		
Clay	<b>-0.811</b>	-0.269
Sand	-0.509	-0.478
<i>Landscape Use</i>		
Forest	<b>1.433</b>	<b>2.499</b>
Grassland	0.684	-0.805
Agriculture	0.526	-0.257
Urban	0.442	-0.585

Note: most significant weights on CCA 1 and CCA 2 are set in bold.

Forested river sub-basin, sand-type substratum, and depth (in order of importance) were the most weighted habitat variables resulting in fish assemblage differentiation in the first ordination axis; forested area, coliform levels, depth, and aquatic vegetation were the parameters mostly correlated with the second ordination axis (Figure 2; Table 4). The CCA diagram also displayed the landscape use profiles that were highly correlated in the stream section's sub-basin. The land use cover of the upper river basin was strongly associated with forested areas, whilst the sub-basins in the midstream sections were greatly correlated with grassland, agricultural land, and urbanized areas. It was also evident in the plot the strong correlation of the downstream sites with several key environmental variables characterizing the condition of the lower river section (deeper, sandy-clay bottom, high concentration of total suspended solids, and high fecal coliform level) (Figure 2).

The indirect and direct gradient analyses divulged the heterogeneity of fish assemblage as a response to the variability of environmental attributes in each stream section. While cichlids are the common inhabitants in the rivers, several native migratory fishes of marine origin are frequent in the lower river sections, whilst enigmatic gobiid species and halfbeaks are affiliated in the semi-pristine areas of the upstream waters. The DCA plots graphically expressed this species' variation along the longitudinal profile of the studied rivers. The fish taxa representing the upstream dwellers positioned at the upper right of the DC plot axis, whereas the extreme upper left of the plot represents the upstream fish assemblages. They are clearly separated to common downstream dwellers (mainly migratory species of marine origin), where species scores are plotted in the extreme right of the axis. The CCA recognized the most significant environmental factors influencing the fish assemblage. The most weighted environmental and habitat

parameters were the structural complexity of substrate types, followed by the depth of the stream sections, and the landscape use. These variables were indicated as good determinants of fish assemblage change, and were determined by several peer-reviewed studies in riverine ecosystems (May & Brown 2000; Humpl & Pivnicka 2006; Tunesi et al 2006; Pritchett & Pyron 2011; Daga et al 2012).

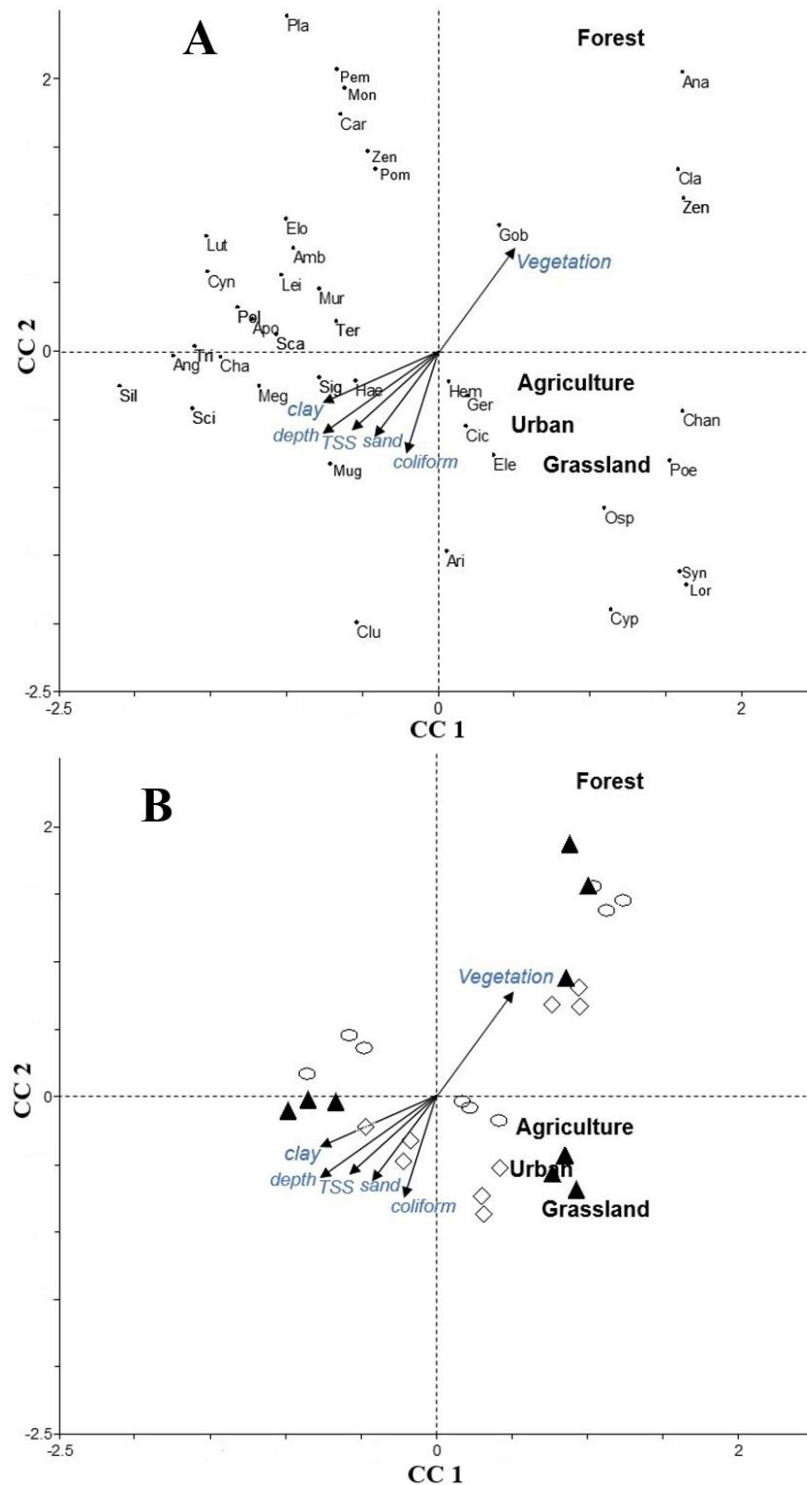


Figure 2. Plot of the first two ordination axes of the canonical correspondence analysis showing the correlations of the most significant environmental variables on the fish assemblages (A) Species scores (See Table 2 for species codes); (B) sampling site scores. Sampling site scores: ◇ Talisay, ○ Bagac, ▲ Almacen; CC 1 = 36.27%, CC 2 = 24.12%.

According to CCA, the substrate was the key environmental parameter structuring the fish assemblage. The structural complexity of substrate type is known to diversify the available microhabitats within the stream sections (Pritchett & Pyron 2011), which further promotes niche partitioning for the adaptive fish species (Matthews 1998; Herder & Freyhof 2006). The second most important parameter identified by the second ordination axis is the variability in depth. Water depth fluctuation is primarily influenced by tidal phase and seasonal changes. The dynamic interplay between brackish water and the inflow of freshwater in the tributaries leads to a remarkable heterogeneity in the fish assemblage (Mercado-Silva et al 2012). As the studied rivers are proximal to seawater, euryhaline species frequent the lower stream reaches apportioning the fish biodiversity gain.

Landscape use is linked to anthropogenically induced landscape and habitat alteration, which are reported as one of the main drivers of change in fish assemblage structure (Kennen et al 2005). The degree of anthropogenic activities, including urban development, agricultural runoff, and pollution, can severely disrupt the natural balance of stream ecosystems (Schleiger 2000). In Bataan, agro-industrialization (Flores et al 2015) and agricultural and domestic run-offs originating from the coastal and upland communities has been identified as one of the major land use issues adversely impacting the abundance of native fishes (Romero et al 2016; Roque et al 2022). These environmental stressors have consequently contributed to the decline of local subsistence fisheries in both coastal and riverine ecosystems (Corpuz & Espaldon 2023).

**Similarity.** A low mean similarity (29.43%) among river sections was observed (Table 5). Spatial dissimilarity among river sections was evident between lower and higher reaches, viz, upstream and downstream sites had no more than 30% level of similarity (13.19±7.28%; 6.48–26.41%), whilst upstream and midstream registered no more than 50% level of similarity (32.25±11.69%; 20.47–45.37%). Midstream and downstream sites also registered a low mean similarity rate of 37.72±13.26% (27.71–64.16%). Moreover, the comparison of studied rivers based on similar river sections showed relatively low similarity rates (upstream: 37.21±11.98%; midstream: 39.61±9.73%; downstream: 47.56±10.02%). The low similarity and low correlation detected among the stream sections conformed with the results of ordination analyses, of which the conspicuous heterogeneity of fish assemblages along the river longitudinal gradient can be attributed to the fluvial environmental attributes and landscape coverage.

Table 5

Bray-Curtis similarity (%) between the studied rivers and their river sections based on fish species and abundance data

	<i>Talisay</i>			<i>Bagac</i>			<i>Almacen</i>			
	<i>U</i>	<i>M</i>	<i>D</i>	<i>U</i>	<i>M</i>	<i>D</i>	<i>U</i>	<i>M</i>	<i>D</i>	
<i>Talisay</i>	<i>U</i>	-	24.32	26.41	49.92	45.36	12.47	35.59	44.69	15.97
	<i>M</i>		-	64.16	5.34	30.44	27.71	6.51	49.82	35.32
	<i>D</i>			-	12.68	37.19	37.60	11.41	47.05	47.45
<i>Bagac</i>	<i>U</i>				-	37.66	6.48	26.12	20.47	9.32
	<i>M</i>					-	31.09	29.10	38.57	32.83
	<i>D</i>						-	7.27	30.85	57.63
<i>Almacen</i>	<i>U</i>							-	21.00	8.52
	<i>M</i>								-	35.20
	<i>D</i>									-

Note: U - upstream, M - midstream; D - downstream.

**Conclusions.** The current findings provide evidence of how environmental attributes and human activities can influence the ecological integrity of fluvial fish communities. Moreover, the study divulged how habitat fragmentation and alteration impact riverine fish communities. From the socio-ecological system perspective, the data can be utilized as basis for predicting the fate of fish assemblage structure as repercussions of

anthropogenically-induced environmental change and habitat loss. The baseline information gathered from this study serves as a critical foundation for implementing effective conservation and management measures, ensuring that conservation strategies align with regional and national environmental policies. Leveraging baseline data can inform immediate conservation actions and contribute to the iterative refinement of policies that govern fishery resource management at multiple levels. This integrative approach is essential for fostering resilience in stream ecosystems, particularly in the face of climate change and increasing anthropogenic pressures in Luzon Island.

This study is one of the few ordination studies employed to assess the ecological health status of river systems in the Central Luzon, Philippines. Thus, incessant periodic investigation is greatly recommended. Similar research initiative can be done in other major inland and coastal waters of Bataan, and other adjacent provinces to assess the impact of habitat alteration and landscape use on the fluvial ecosystem health, with ichthyofauna as the main bioindicator.

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**Conflict of Interest.** The authors declare that there is no conflict of interest.

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