Key environmental and habitat variables affecting the fish assemblages in Bagac River systems, Bataan, Philippines

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Abstract. The present study investigated the association of riverine fishes and environmental variables in the poorly-evaluated Bagac River systems, Luzon Island, Philippines. Fish samples were obtained using a stupefying method and cast netting, and physico-chemical parameters were recorded in each stream section (upstream, midstream, downstream). The study inventoried 400 specimens belonging to 15 fish species from at least 10 different families. Native fishes predominated the fish species composition comprising 12 out of 15 identified fish specimens. The five different fishes that comprised 68.39% of the total abundance were *Oreochromis niloticus* (17.10%), *Zenarchopterus buffonis* (16.58%), *Clarias batrachus* (13.47%), *Ambassis gymnocephalus* (11.92%), and *Sarotherodon melanotheron* (9.33%). Log-transformed abundance data were used in direct gradient ordination analysis (canonical correspondence analysis, CCA). From the 18 environmental variables, CCA (88.98% variation on the first and second ordination axes) identified substratum types, vegetation, and temperature (in order of importance) as the most important causative environmental variables affecting the fish assemblages. Morisita-Horn similarity analysis using species and abundance data scored a low similarity (10%) between upstream and midstream-downstream groups. The midstream and downstream registered a 47.36% level of similarity. The apparent heterogeneity of fish assemblages as influenced by river environmental parameters recognized the need to comprehend how anthropogenically-induced disturbance can impact the diversity and distribution of riverine fishes.

Key Words: CCA, fish densities, Luzon, native fishes, ordination analysis.

Introduction. River ecosystems have vital contributory roles in global ecosystems, economic growth and social integrity (Liyanage & Yamada 2017). However, continuous population growth (Rabadon & Corpuz 2021), pollution (Wu et al 2019), and climate change (Qui et al 2019) have threatened riverscapes and river fishery resources globally. These factors have led to the displacement of fish assemblages, leading to a conspicuous decline in fish biodiversity and yield (Su et al 2021).

Fish assemblages and environmental characters of aquatic ecosystems are considered good indicators of ecosystem health (Sheaves et al 2012; Huang et al 2019). Fish assemblages, in particular, are excellent bioindicators as they are sensitive to changes and they are capable of integrating the effects of multiple stressors in aquatic ecosystems (Karr et al 1986). Information on water quality could provide insight into the present well-being of the environment (Kotti et al 2005) and could aid in identifying the actual and emerging problems of water bodies. Fish communities and water quality information are therefore viable prerequisites for the successful formulation and implementation of conservation and management strategies (Paller et al 2013; Holguin-Gonzales et al 2014; Corpuz et al 2015).

Understanding the influence of abiotic factors in stream fish assemblages has a crucial role in the conservation of vulnerable riverine fishes and aquatic biota (Romero et al 2016; Krisanti et al 2020). Several studies on quantitative community ecology have been employed to shed light on the repercussion of changes in key environmental variables structuring the fish assemblages, studies such as fisheries integrity (Gebrekiros

2016), and impact on the socio-economic aspect in the riparian community (Triyanto et al 2020; Soukhaphon et al 2021). Multivariate direct ordination analyses have been used to primarily assess the relationship of environmental variables and ichthyofaunal assemblages in various aquatic habitats (May & Brown 2000; Corpuz et al 2016; Huang et al 2019).

In the Philippines, ecological studies on freshwater systems have been receiving ample attention recently (Paller et al 2011; Magbanua et al 2017). This is a good indication that local scholars and experts have been recognizing the importance of assessment studies on the formulation of effective management strategies. The Bagac River system is among the riverine systems in the Philippines that have not been given much emphasis in the field of research and development (Roque et al 2019). The poorly evaluated conservation status of the river system is leading to the lack of community awareness that has resulted in imprudent utilization of its resources. To date, there was no study focused on assessing the ecological well-being of the river that may potentially serve as a future reference to the conservation management of this precious natural asset. To date, there is no quantitative community ecological study focusing on the influence of environmental variables on stream fish assemblages. Thus, the present study evaluated the most influential environmental variable that affects the fish assemblages of Bagac River systems. Moreover, the study provided updated baseline information on the diversity, abundance, and distribution of ichthyofaunas in each stream section.

Material and Method

Study areas. Fish specimens and water samples for physico-chemical analyses were collected from the three river sections of the Bagac River systems in Bataan, Philippines (Figure 1). The river is located in the northwestern portion of Mount Mariveles (Luzon Island) and water-fed by the springs and run-offs from highlands and adjacent tributaries before emptying to the West Philippine Sea. The upstream (14°38'11.7" N; 120°27'06.5" E) is characterized by a substratum composed mainly of cobble and boulder, a typical feature of a mountain stream. Riverbanks are flattened and being used for rice and coconut plantation. The midstream (14°35'45" N; 120°23'45" E) presented gravel to sandy watershed and mainly surrounded by rice plantation, perennial weeds, and several human settlements. The downstream (14°35'30" N; 120°23'23" E) is situated in the village main area, with few patches of mangroves and riparian grassland. Local villagers are mostly engaged in capture fisheries, farming, and handicraft industry. The sampling areas have two pronounced seasons, a dry season from November to May and a wet season during the rest of the year.

Fish collection. Nine stations were selected as sampling sites, i.e., three longitudinal sub-sections measuring about 60 meters were designated in each stream section (upstream, midstream, downstream), and were selected to cover the distinct habitat types in every river section. Fishes were stupefied using a 12-v backpack electrofishing gear and were scooped using hand nets. Individual sampling lasted for about 30 min and was done during the daytime. Captured fish specimens were immediately counted and determined to the lowest possible taxon. Several fish specimens were preserved in a 5% buffered formaldehyde solution for further documentation and identification purposes. Juvenile fishes and those that are identified as native specimens were released after in-situ identification. Specimens were identified using several fish identification materials and related works (Herre 1924; Paller et al 2013; Corpuz et al 2016; Froese & Pauly 2019).

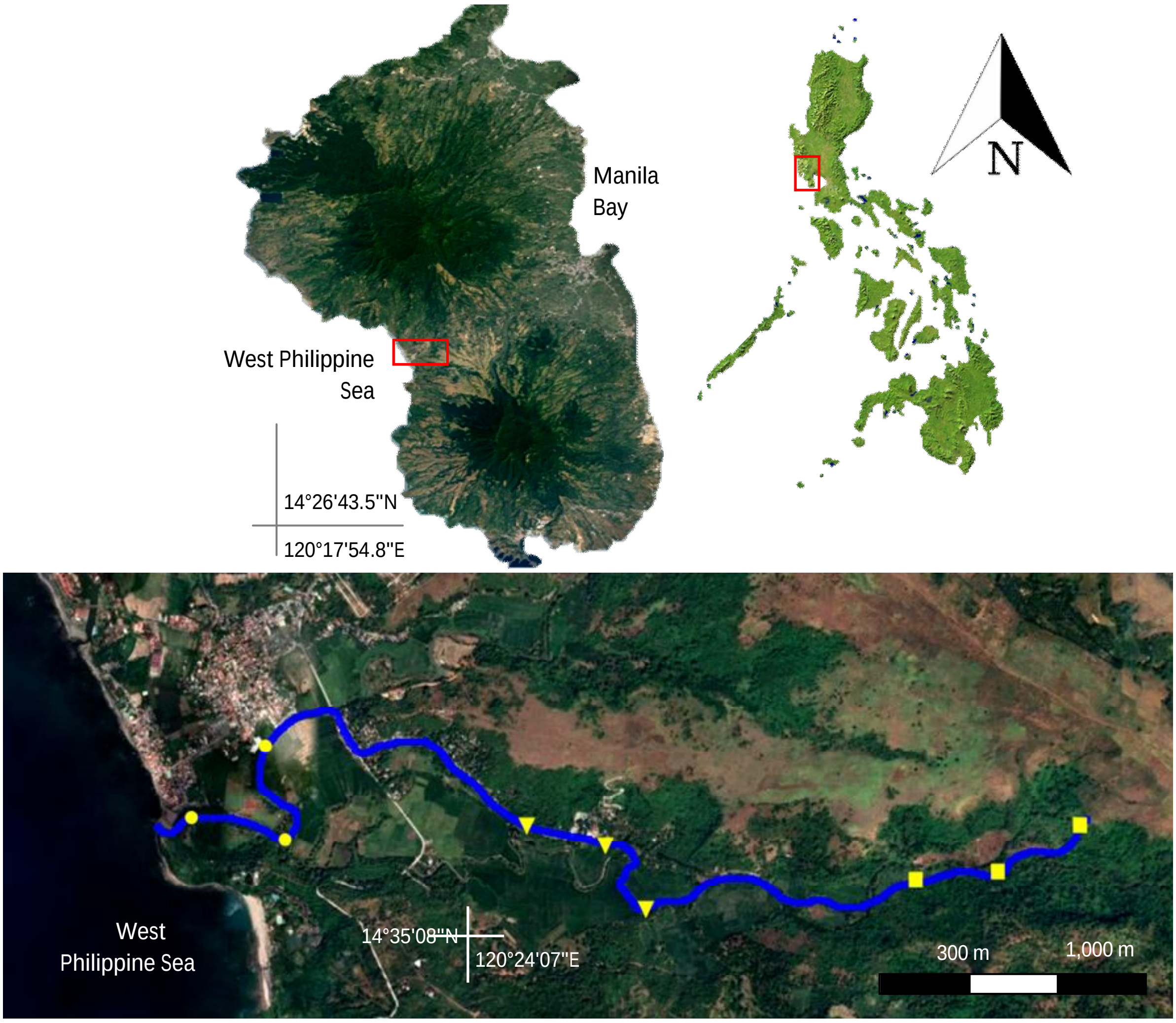

Figure 1. Map of Bagac river showing the studied riverine sections.
Sampling sites: ● downstream, ▼ midstream, and □ upstream.

Water quality and environmental variables. In the sampling areas, water quality parameters and habitat characteristics were recorded. These parameters include dissolved oxygen (DO, Hanna HI 3810), temperature (°C), pH (Oakton pH tester 30), and salinity (Atago hand refractometer). Ammonia (NH_3), nitrate (NO_3), and nitrite (NO_2) were sampled using an ammonia test kit. Mean depth (cm) was measured using a meter rule and water flow (m s^{-1}) was recorded using a simple float. Substrate type was characterized according to the particle size of the bed element, such as detritus, silt, mud, sand (0.02-2 mm), gravel (2-64 mm), cobble (64-256 mm), or boulder (256 mm) (May & Brown 2000). Vegetation cover (%) was estimated visually at the time of sampling according to the relative amount of the presence of foliage in the riparian zone as well as submerged or floating hydrophytes along the sampling path. Landscape use patterns and the number of housing units were also recorded.

Data analyses. Fish densities (number of individuals collected in one species/100 m^2) and relative abundances (number of individuals collected in one species/the total number of species collected) were determined for every stream section. Pooled fish density, however, did not follow the normality assumptions (Shapiro-Wilk test), and as such, the fish density data were subjected to the Friedman test to determine the spatial variability among and between the three-stream sections ($p < 0.05$).

Abundance data were log10 (x+1)-transformed prior to ordination analyses. Descriptive statistics of environmental variables were also computed. All variables that met the parametric assumptions were subjected to ANOVA, and post-hoc Tukey's HSD test (p < 0.05). Reduction analysis using Spearman's rank-order correlation coefficients (r_s) was performed to exclude the redundant variables. Only the factors with r_s < 0.32 (α < 0.05) were retained for principal component analysis (PCA). Further reduction analysis of significant environmental variables was done using correlation matrix of PCA. Five variables were eliminated including pH, NH_3, NO_3, NO_2, and water velocity.

The direct gradient analysis (canonical correspondence analysis, CCA) was used to examine the association of the fish species data from nine sampling sites with the most significant environmental variables. The multivariate statistics also identified environmental variables correlated maximally with fish species and site variance. Significant variability among fish assemblage, sites, and environmental variables was tested using the Monte-Carlo test with 999 random permutations and forward selection ($p < 0.05$) (Ter Braak & Verdonschot 1995). Morisita-Horn similarity index was used for multi-group comparison among the stream sections. The unweighted pair group method with arithmetic mean was also applied to cluster the riverine groups according to species and standardized abundance data. All statistical analyses were performed using Paleontological Statistics v 3.0 and Statistica v 6.0.

Results and Discussion

Environmental and habitat variables. Abiotic and habitat characteristics of the three-stream sections of the Bagac river system are summarized in Table 1. Water temperature of midstream (29.13±0.59°C) and downstream (27.10±0.60°C) were homogenous but were higher than in the upstream (24.97±0.15°C). The mean pH levels were slightly alkaline; highest pH readings were recorded in the midstream (8.23±0.10). Salinity readings were recorded in the downstream (0.17±0.06 g L^{-1}). Although fluctuating, the DO readings in the midstream (4.53±0.10 mg L^{-1}), downstream (4.77±0.10 mg L^{-1}), and upstream (6.88±0.46 mg L^{-1}) were relatively comparable. The NH_3 and NO_2 were recorded in the downstream, whilst NO_3 was undetectable in all sampling sites. Mean depth of upstream and midstream were both less than a meter, albeit the downstream had about 2.00 m.

Table 1

Abiotic (mean±SD) and habitat characteristics of the three sampling sites

Environmental and habitat variables	*Upstream*	*Midstream*	*Downstream*	*F value*
DO (mg L^{-1})	6.88 ± 0.46^{a}	4.53 ± 0.10^{b}	4.77 ± 0.10^{b}	1.55^{NS}
Temperature (°C)	24.97 ± 0.15^{c}	29.13 ± 0.59^{a}	27.10 ± 0.60^{b}	69.43**
pH	7.95 ± 0.17^{ab}	8.23 ± 0.10^{a}	7.45 ± 0.80^{b}	31.82*
NH_3 (mg L^{-1})	0	0	0.08±0.01	-
NO_3 (mg L^{-1})	0	0	0	-
NO_2 (mg L^{-1})	0	0	0.07±0.01	-
Depth (m)	0.59 ± 0.15^{b}	0.24 ± 0.09^{b}	2.00 ± 0.92^{a}	10.67*
Water velocity (m s^{-1})	0.47 ± 0.21^{a}	0.25 ± 0.08^{a}	0.08±0.11b	5.55*
Salinity (g L^{-1})	0	0	0.17 ± 0.06	-
Visibility depth (m)	0.72 ± 0.11^{a}	0.46 ± 0.14^{b}	0.34 ± 0.02^{b}	9.16*
Substrata	Large boulders, cobbles, bedrock.	Gravels, cobbles, sand.	Sand, mud, organic detritus.	
Dominant vegetation observed	Bryophytes, crops in riparian zone.	Bryophytes, perennial weeds, *Oryza sativa*.	Mangroves, riparian macrophytes.	

**significant at 1% level of confidence; *significant at 5% level of confidence; NS not significant at 5% level of confidence; for each abiotic variable, means with the same superscript letter are not significantly different at 5% level of confidence.

Fish abundance and composition. Overall, the fish survey collected a total of 400 fish individuals belonging to at least 10 different families (Table 2). In terms of fish species composition, Family Gobiidae was the most dominant (5 species) and followed by Cichlidae (2 species). The three stream sections were characterized by dissimilar species occurrence, albeit the family Clariidae was the only common fish family present in all three sampling sites. Ten species were recorded in the downstream, eight in midstream, and five in the upstream. Three fish species were categorized as non-native, whilst 12 were native fish species. Highest fish abundance was recorded in the midstream (n = 174), followed by downstream (n = 147), and upstream (n = 79). The five most abundant fishes that comprised 68.39% of the total number of collected fish specimens were *Oreochromis niloticus* (17.10%), *Zanarchopterus buffonis* (16.58%), *Clarias batrachus* (13.47%), *Ambassis gymnocephalus* (11.92%), and *Sarotherodon melanotheron* (9.33%). Pooled fish density was not significantly different among the three sampling sites (Friedman test: $\chi2 = 0.094$, $p > 0.05$).

Table 2

Distribution and relative densities (individual per 10 m^2) of ichthyofaunas along the three river sections of the Bagac River system

Family	*Scientific name*	*Common name*	*Code*	*Sampling sites (stream sections)*		
				Up	*Mid*	*Down*
Ambassidae	*Ambassis gymnocephalus* (Lacepède, 1802)	Bald glassy	*Agym*	0	0	0.828
Anguilidae	*Anguilla marmorata* Quoy & Gaimard, 1824	Giant-mottled eel	*Amar*	0.277	0	0.207
Cichlidae*	*Oreochromis niloticus* (Linnaeus, 1758)	Nile tilapia	*Onil*	0	2.279	0
Cichlidae*	*Sarotherodon melanotheron* Rüppell, 1852	Blackchin tilapia	*Smel*	0	0.829	0.414
Channidae*	*Channa striata* (Bloch, 1793)	Snakehead murrel	*Cstr*	0	0.414	0.07
Clariidae	*Clarias batrachus* (Linnaeus, 1758)	Asian catfish	*Cbat*	1.525	0.207	0.07
Dasyatidae	*Himantura* sp.	Stingray	*Hims*	0	0	0.07
Gobiidae	*Glossogobius giuris* (Hamilton, 1822)	White goby	*Ggiu*	0	0.76	0.483
Gobiidae	*Glossogobius* sp.	Flat goby	*Glos*	0	0.092	0
Gobiidae	*Rhinogobius* sp.	Round goby	*Rhis*	0.07	0.07	0
Gobiidae	*Sicyopus* sp.	Goby	*Sics*	0.485	0	0
Gobiidae	*Stiphodon* sp.	Riffle goby	*Stis*	0.208	0	0
Lutjanidae	*Lutjanus argentimaculatus* (Forsskål, 1775)	Mangrove red snapper	*Larg*	0	0	0.552
Mugilidae	*Mugil cephalus* Linnaeus, 1758	Grey mullet	*Mcep*	0	0	0.207
Zenarchopteridae	*Zenarchopterus buffonis* (Valenciennes, 1847)	Buffon's river-garfish	*Zbuf*	0	1.036	1.173

*non-native fish species (Froese & Pauly 2019); Up - upstream; Mid - midstream; Down - downstream.

The conspicuous feature of Bagac River systems is the apparent disparity of fish assemblages thriving in each of its three-stream sections. The present finding is comparable to the observed diversity and distribution of other tropical riverine ichthyofaunas in the Philippines (Corpuz et al 2016; Paller et al 2017). Upstream fish communities are largely represented by native diminutive fishes, particularly several enigmatic gobies (e.g., neon gobies) that are known to be adaptive in rapid and cool lotic ecosystems (Corpuz 2011; Romero et al 2016; Roque et al 2019). The downstream was found to be predominated by euryhaline fish species which are being caught and utilized by local fisherfolks for subsistence consumption. The invasion of non-native cichlids in lower stream section can be the repercussion of the periodic deliberate release of hatchery-bred juvenile tilapias by the Bureau of Fisheries and Aquatic Resources under the river rehabilitation project of the Philippine government (Municipal Fisheries Officers, personal communication). While three species of non-native fishes dominated the relative abundance, native fishes still comprised a larger proportion in terms of species richness/composition (12 out of 15 fish species). Furthermore, the absence of alien fish species in the upstream suggests an insignificant impact of anthropogenic disturbance (Kennard et al 2005; Paller et al 2017), benefiting the native fish populations in the upstream.

Fish assemblage and environmental variables. The PCA for significant environmental variables extracted from the correlation matrix exhibited a cumulative variation of 77.19%. The most important variable weightings in PC1, in order of significance, were substrate type, salinity, vegetation, and depth (all loaded positively), whilst PC2 identified temperature as the main contributor of variation (Table 3). These five parameters were retained and included in direct ordination analysis (i.e., CCA) for environment-fish data.

Table 3

Relative eigenvalues, PC variation, and weights of important environmental variables for two principal components. Most weighted parameters of PC1 and PC2 are set in **bold** font (Jolliffe Cut-off: 0.875)

Eigenvalue	*PC 1*	*PC 2*
	5.518	*2.20*
% Variation	*55.199*	*21.996*
Eigenvectors		
Dissolved oxygen	-0.493	0.792
Temperature	0.014	**-0.969**
pH	-0.862	-0.367
NH_3	0.629	0.108
NO_2	0.417	0.001
Depth	**0.914**	0.212
Current	-0.654	0.567
Salinity	**0.958**	0.011
Vegetation	**0.922**	0.326
Substrate type	**0.967**	-0.119

The environment-fish data were highly significantly different among the three stream sections ($p < 0.01$) (Figure 2; Table 4). In CC1 (variation = 55.71%), midstream and downstream were diverged from downstream, whilst in CC2 (variation = 33.27%), downstream were relatively deviated from the two sampling groups (Figure 2). The site-environment and species-environment relationships outlined by the CCA had eigenvalues of 0.728 and 0.425 on the first two axes, with 88.98% variation in fish assemblages explained (Table 4).

Table 4

Relative eigenvalues, % variation, and weights of important environmental variables for two ordination axes components. Most weighted parameters of CC 1 and CC2 are set in **bold** font

Eigen value	*CC 1*	*CC 2*
	0.728	*0.425*
% Variation	*55.711*	*33.269*
Eigenvector		
Temperature	-0.03	**0.956**
Depth	-0.586	-0.666
Salinity	-0.453	-0.821
Vegetation	**0.947**	-0.249
Substrate type	**0.948**	0.227

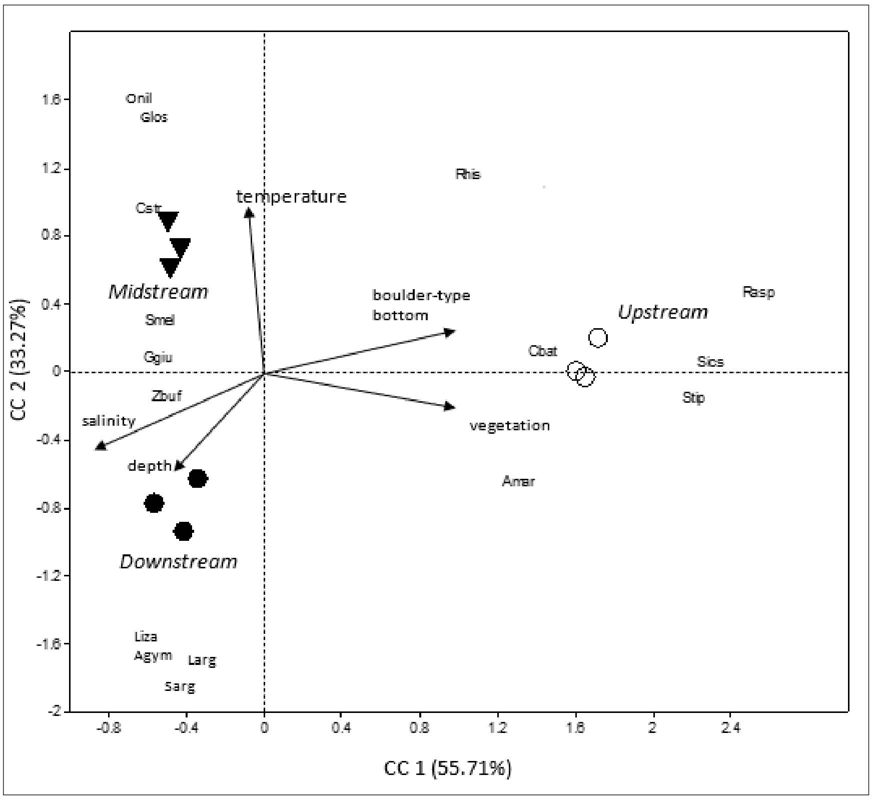

Figure 2. Plot of the first two ordination axes of the canonical correspondence analysis showing the interest correlations of the most significant environmental variables with the fish assemblages (Table 1 for species code). Sampling sites: ● downstream, ▼ midstream, and ○ upstream.

The CCA ordination described the variability in fish assemblages as a function of changes in the longitudinal gradient feature of the three stream sections. In the CCA diagram, boulder-type substrate and high vegetation cover were highly correlated with the upstream; midstream had higher temperature readings, whereas the downstream had higher salinity and deeper water. Overall, the final CCA identified substratum types, vegetation, and temperature (in order of importance) as the most weighted causative habitat variables affecting the fish assemblage (Table 4).

The present findings provide evidence that spatial variability in abundance and composition of riverine fish faunas is highly influenced by integrative environmental parameters. In lotic environments, large substrate materials (e.g., gravel, cobble, and boulders) increase the variety of microhabitats that can accommodate a greater and more diverse range of fish species (May & Brown 2000; Zeni et al 2019). Diminutive fishes like gobies usually use the pools and interstitial spaces between these large substrates for refuge and breeding grounds (Ter Braak & Verdonschot 1995; Corpuz 2011; Gebrekiros 2016). However, a low concentration of large substrates is prone to higher levels of sedimentation and siltation, which can lower the abundance and diversity of benthic fish communities (Iwata et al 2003). Conversely, the homogeneity of small-sized substrates benefits the localized movement of nektonic fishes (Deacon & Mize 1997).

Several reports have recognized the vital role of riverscape vegetation and forest cover in the induced functional fish diversity (Wang et al 2013; Arantes et al 2018). Aside from its occurrence, the type of vegetation could also influence fish diversity. In a freshwater river in East China, more fish species were found in areas dominated by floating-leaved macrophytes than those areas with emergent vegetation (Wang et al 2013). Moreover, areas rich with vegetation (e.g., mangroves) provide greater heterogeneity of resources that could support a wider range of species, thereby promoting diversity (Flores et al 2016). The linear relationship between fish diversity and abundance with vegetation and forest cover is associated with complex mechanisms that provide refuge, breeding, and feeding sites for fish communities (Wang et al 2013; Corpuz et al 2015; Arantes et al 2018).

Based on CC2, temperature plays a major role in the distribution of fish assemblages of the Bagac River systems. Temperature as a limiting factor has since been known to affect the behavior and distribution of freshwater organisms (McCann et al 2018; Nadermann et al 2019). In this study, the highest temperature readings recorded in the midstream can be attributed to the loss of naturally-occurring vegetation including *Nypa fruticans*.

Similarity. Morisita-Horn similarity analysis for species composition and abundance divulged the clustering of stream sections of Bagac (Figure 3).

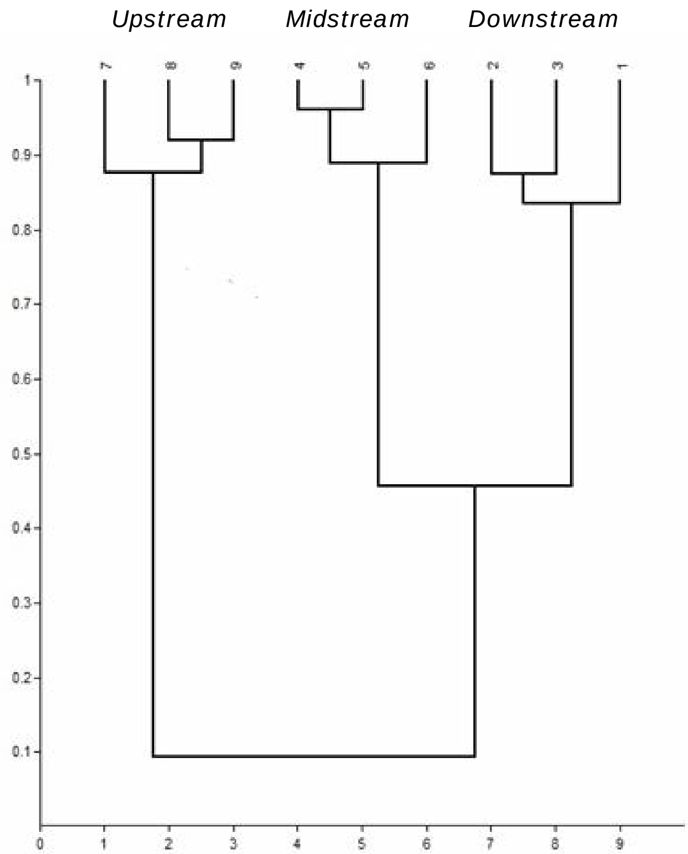

Figure 3. A dendrogram from the unweighted pair group method with arithmetic means showing the relationship of stream sections based on fish taxa and log-transformed abundance data.

A low similarity was observed between upstream and midstream-downstream sampling groups, having not more than a 10% level of similarity. The midstream and downstream registered a 47.36% level of similarity. It is apparent that several fish faunas are restricted in a particular stream section of Bagac. This spatial divergence signifies disparity of fish assemblages despite their distribution in a small-sized river, albeit restricted in a particular stream sub-habitat. This is remarkably observable in headwaters that serve as a haven for several diminutive fish communities. Massive alteration of key habitats in the river may significantly affect the abundance and distribution of the fishes. Changes in key environmental variables may dictate the fate of survival of several stenotopic fishes, mostly native species that are vulnerable to a multitude of environmental pressures (Cheng et al 2010; Su et al 2021).

Conclusions. The present study sheds light on the influence of environmental and habitat variables on the fishes thriving in Bagac River. The information can be used to predict the fate of fish assemblages amidst the presence of anthropogenic disturbance; this will serve as a basis for the refinement of the conservation plans and programs for this riverine aquatic resource. Further investigation can be done with emphasis on temporal variation of fish assemblages coupled with studies on their feeding ecology and reproduction. Previous initiatives on fish survey can be replicated for Central Luzon, Philippines, with high attention to the socio-ecological system and the association of fish-environment data with that of the local fishery activities.

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

References

Arantes C. C., Winemiller K. O., Petrere M., Castello L., Hess L. L., Freitas C. E. C., 2018 Relationships between forest cover and fish diversity in the Amazon River floodplain. Journal of Applied Ecology 55(1):386-395.

Cheng L., Lek S., Loot G., Lek-Ang S., Li Z., 2010 Variations of fish composition and diversity related to environmental variables in shallow lakes in the Yangtze River basin. Aquatic Living Resources 23(4):417-426.

Corpuz M. N. C., 2011 Morphological variations, sexual dimorphism, and gonadal analysis of populations of the Celebes goby, *Glossogobius celebius* (Perciformes: Gobiidae) from Southern Luzon, Philippines. MSc thesis, University of the Philippines Los Baños, College, Laguna, Philippines, 123 p.

Corpuz M. N. C., Paller V. G. V., Ocampo P. P., 2015 Environmental variables structuring the stream gobioid assemblages in the three protected areas in southern Luzon, Philippines. Raffles Bulletin of Zoology 63:357-365.

Corpuz M. N. C., Paller V. G. V., Ocampo P. P., 2016 Diversity and distribution of freshwater fish assemblages in Lake Taal River systems in Batangas, Philippines. Journal of Environmental Science and Management 19(1):85-95.

Deacon J. R., Mize S. V., 1997 Effects of water quality and habitat on composition of fish communities in the Upper Colorado River Basin. US Geological Survey Fact Sheet 122-97, Denver, Colorado, 6 pp.

Flores R. C., Corpuz M. N. C., Salas J. M., 2016 Adoption of aquasilviculture technology: a positive approach for sustainable fisheries and mangrove wetland rehabilitation in Bataan, Philippines. International Journal of Food Engineering 2(1):79-83.

Froese R., Pauly D. 2019 Fishbase. World Wide Web electronic publication. Available at: www.fishbase.org. Accessed: October, 2019.

Gebrekiros S. T., 2016 Factors affecting stream fish community composition and habitat suitability. Journal of Aquaculture and Marine Biology 4(2):00076.

Herre A. W. C. T., 1924 Distribution of true freshwater fishes in the Philippines. I. The Philippine Cyprinidae. Philippine Journal of Science 24(3):249-307.

Holguin-Gonzalez J. E., Boets P., Everaert G., Pauwels I. S., Lock K., Gobeyn S., Benedetti L., Amerlinck Y., Nopens I., Goethals P. L. M., 2014 Development and assessment of an integrated ecological modelling framework to assess the effect of investments in wastewater treatment on water quality. Water Science and Technology 70(11):1798-1807.

Huang J., Huang L., Wu Z., Mo Y., Zou Q., Wu N., Chen Z., 2019 Correlation of fish assemblages with habitat and environmental variables in a headwater stream section of Lijiang River, China. Sustainability 11(4):1135.

Iwata T., Nakano S., Inoue M., 2003 Impacts of past riparian deforestation on stream communities in a tropical rain forest in Borneo. Ecological Applications 13(2):461-473.

Karr J. R., Fausch K. D., Angermeier P. L., Yant P. R., Schlosser I. J., 1986 Assessing biological integrity in running waters: a method and its rationale. Illinois Natural History Survey Special Publication 5, 26 pp.
Kennard M. J., Arthington A. H., Pusey B. J., Harch B. D., 2005 Are alien fish a reliable indicator of river health? Freshwater Biology 50(1):174-193.
Kotti M. E., Vlessidis A. G., Thanasoulias N. C., Evmiridis N. P., 2005 Assessment of river water quality in Northwestern Greece. Water Resources Management 19:77-94.
Krisanti M., Maknuun L. L. I., Anzani Y. M., Yuwono A. S., Widyastuti R., Wardiatno Y., Wulandari D., 2020 A comparative study on macroinvertebrates community in three rivers of Jawa Island, Indonesia. AACL Bioflux 13(2):570-581.
Liyanage C. P., Yamada K., 2017 Impact of population growth on the water quality of natural water bodies. Sustainability 9(8):1405.
Magbanua F. S., Fontanilla A. M., Ong P. S., Hernandez M. B. M., 2017 25 years (1988-2012) of freshwater research in the Philippines: what has been done and what to do next? Philippine Journal of Systematic Biology 11(1):1-15.
May J. T., Brown L. R., 2000 Fish community structure in relation to environmental variables within the Sacramento River Basin and implications for the greater Central Valley, California. US Geological Survey Report 00-247, Sacramento, California, 19 pp.
McCann E. L., Johnson N. S., Pangle K. L., 2018 Corresponding long-term shifts in stream temperature and invasive fish migration. Canadian Journal of Fisheries and Aquatic Sciences 75(5):772-778.
Nadermann N., Seward R. K., Volkoff H., 2019 Effects of potential climate change-induced environmental modifications on food intake and the expression of appetite regulators in goldfish. Comparative Biochemistry and Physiology. Part A: Molecular and Integrative Physiology 235:138-147.
Paller V. G. V., Corpuz M. N. C., Ocampo P. P., 2013 Diversity and distribution of freshwater fish assemblages in Tayabas River, Quezon (Philippines). Philippine Journal of Science 142(1):55-67.
Paller V. G. V., Corpuz M. N. C., Bandal Jr. M. Z., 2017 Freshwater fish assemblages and water quality parameters in seven lakes of San Pablo, Laguna, Philippines. Asian Journal of Biodiversity 8:1-22.
Paller V. V., Ocampo P. P., Corpuz M. N. C., 2011 Fish Ark Philippines: direction for the conservation of native and endemic Philippine Freshwater Fishes Project 1: Survey of diminutive freshwater fishes indigenous to isolated crater lakes, mountain crater lakes, mountain streams and cataracts in Southern Luzon, Philippines. Available at: http://agris.fao.org/agris-search/search.do?recordID=PH2012000274. Accessed: October, 2021
Qui H., Niu J., Hu B. X., 2019 Quantifying the integrated water and carbon cycle in a data-limited karst basin using a process-based hydrologic model. Environmental Earth Sciences 78:328.
Rabadon M. L. L., Corpuz M. N. C., 2021 Multivariate analyses of selected hydro-bacterial variables along the longitudinal gradient of Orani River, Philippines. IOP Conference Series: Earth and Environmental Science 798(1):012004.
Romero C. S., Villaflor K. C., dela Rosa D., Corpuz M. N. C., 2016 Environmental variables affecting the riverine ichthyofaunas and macroinvertebrate communities in Orani river systems (Tala-Silahis continuum), Bataan, Philippines. 2nd International Conference in Research, Education, Management, and the Social Sciences, Harbour Hotel, Canal Road, Subic Bay Freeport Zone, Zambales, pp. 31-48.
Roque N. B. C., Corpuz M. N. C., Manliclic A. D. C., 2019 Rapid bioassessment and ordination analysis of fish assemblages in Bagac river systems, Bataan, Philippines. Proceedings of the 2nd National Conference on Food, Environment, Engineering and Technology (2nd NCFEET), vol. 2, pp. 33-37.
Sheaves M., Johnston R., Connolly R. M., 2012 Fish assemblages as indicators of estuary ecosystem health. Wetlands Ecology and Management 20:477-490.
Soukhaphon A., Baird I. C., Hogan Z. S., 2021 The impacts of hydropower dams in the Mekong River basin: a review. Water 13(3):265.
Su G., Logez M., Xu J., Tao S., Villeger S., Brosse S., 2021 Human impacts on global freshwater fish biodiversity. Science 371(6531):835-838.

Ter Braak C. J. F., Verdonschot P. F. M., 1995 Canonical correspondence analysis and related multivariate methods in aquatic ecology. Aquatic Sciences 57(3):255-289.
Triyanto, Affandi R., Kamal M. M., Haryani G. S., 2020 Population dynamic and exploitation rate of glass eels (*Anguilla* spp.) in Cimandiri River estuary, West Java, Indonesia. AACL Bioflux 13(2):529-538.
Wang J., Song X., Zou G., Zhou W., 2013 Effects of aquatic vegetation on fish assemblages in a freshwater river of Taihu lake basin, East China. Journal of Water Resource and Protection 5(1):37-45.
Wu D., Lu A., Tian S., Yin X., Zhang Y., Xu Z., 2019 Quantitative analysis of the diversity and habitat suitability of the Huntai River fish community. China Environmental Science 39(11):4875-4885.
Zeni J. O., Pérez-Mayorga M. A., Roa-Fuentes C. A., Brejao G. L., Casatti L., 2019 How deforestation drives stream habitat changes and the functional structure of fish assemblages in different tropical regions. Aquatic Conservation: Marine and Freshwater Ecosystems 29(8):1238-1252.

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