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First insight into freshwater fish assemblages in the western part of the Endau-Rompin landscape, Malaysia

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Abstract

In Malaysia, our knowledge of freshwater ecosystem and its aquatic inhabitants, particularly freshwater fish, remains inadequate, even in protected regions. It is essential to understand the composition of freshwater fish, their distribution along river gradients, and their interactions between environmental variables to develop and strategize effective conservation and management plans. Consequently, an investigation into freshwater fish assemblages in three rivers draining off from the western part of Endau-Rompin Landscape was conducted in 12 established substations. Sampling sessions were conducted from September to December 2021 in the Labis district of Johor, using multiple sampling methods along 200 meters for each substation. The environmental variables were measured using water quality parameters. A total of 66 species were collected. The family Cyprinidae presented the highest species diversity (17 species), constituting 52% of total capture. *Crossocheilus obscurus* was the most dominant species, and the highest species richness was recorded in the Segamat River (45 species), followed by Juaseh (36 species) and Labis River (34 species). It was discerned that the composition of fish varied between the substations. The knowledge presented here is the first documentation on the freshwater fish from these rivers. It would serve as a baseline information for key authorities and stakeholders to conserve the biodiversity inhabiting freshwater ecosystems in Malaysia.

Keywords
conservation, diversity, ichthyology, redundancy analysis, species richness

Introduction

The surface freshwater habitats contain only approximately 0.01% of the world's water volume and cover only roughly 0.8% of the Earth's surface (Gleick 1996; Reid et al. 2019; Miller 2021; Val et al. 2022). Yet, it is home to a vast number of species and broadly used by human for various ecosystem services. The decline of freshwater biodiversity is far greater than in most affected other terrestrial ecosystems (Sala et al. 2000; Darwall et al. 2018; Harrison et al. 2018; Reid et al. 2019; Tickner et al. 2020). Currently, the rate of wetland loss is three times that of forest loss (Gardner and Finlayson 2018), and populations of freshwater vertebrate species have declined at twice the rate of that involving land or ocean vertebrates (Grooten and Almond 2018). Reid et al. (2019) recognized that threats, such as water pollution, overexploitation, flow modification, destruction or degradation of habitat, and invasion by exotic species persist to the present, as reviewed by Dudgeon et al. (2006) a decade ago with 12 more stressors that implicate the freshwater biodiversity globally. Similar threats to the freshwater ecosystems were reported in Malaysia and these will assuredly endanger the freshwater ecosystem and biodiversity.

Rivers in Malaysia are rich ecosystems with wider functions, including providing water supply, irrigation for agriculture, a means of transportation, a source of food (fisheries), hydroelectric power, and water use for industries (Chan 2002). Rivers are also habitats for riverine and aquatic flora and fauna, and the riparian environment supports a rich biodiversity of life forms (Naiman and Bilby 1998). However, over the years, the water quality of rivers has been substantially damaged due to a combination of factors, namely the low priority accorded to it by the government, public apathy, negligence, and bad management. (Chan 2012). With the rapid destruction of natural habitats along the freshwater ecosystem, it is essential to document the presence, diversity, and distribution of fauna, especially the freshwater fish in various inland water bodies in Malaysia.

Fishes are important ecological components of the freshwater ecosystem, and they are one of the animals currently threatened in Malaysia. According to Chong et al. (2000) habitat deterioration, loss, and change threaten almost 76% of freshwater fish species in Malaysia. Furthermore, Malaysian freshwater fish documentation remains in its early stages, and no centralized taxonomy oversight exists (Ng et al. 2017; Ng et al. 2019). Baseline information on the diversity and distribution of the species of concern is essential for developing holistic conservation and management strategies. In fact, knowledge of freshwater fish present across protected areas and surrounding ecosystems in Malaysia remains poor and inadequate.

Endau-Rompin Landscape (**ERL**) comprises two major protected forest lands; Rompin State Park (**RSP**) which is located in the State of Pahang while Endau-Rompin Johor National Park (**ERJNP**) of Johor is administered by the Johor National Parks Corporation. The ERJNP is surrounded by several permanent forest reserves including the Labis, Mersing, Kluang, Lenggor and Ulu Sedili Permanent Reserved Forests and managed by Johor Forestry Department. The ERL itself encompassed 3,600 km^2 of total coverage.

The ERL is located within a matrix of other land cover types, especially oil palm and rubber plantations to the north, west, and south (Saaban et al. 2020). The landscape was well-chronicled for its large mammals, including tigers and elephants, and the conflicts triggered by these large animals. Studies on other fauna groups were also well-established, especially within RPS and ERJNP. While the gazettement safeguarded the RPS and ERJNP, the forest reserves surrounding the protected forest land faced an onslaught of threats ranging from land-use conversion to agricultural and infrastructural development (Aqilah et al. 2018). It is time to initiate a comprehensive study on the ecosystem and diversity found within these forest reserves, particularly the freshwater fish assemblages that remain unassessed.

The main aim of this study was to document the freshwater fish assemblages in three rivers that flow off from the Labis Forest Reserve, a forest complex next to ERL. Second, we aim to verify if the composition of fish changes gradually along the river gradient and if the fish composition differs between the substations as well. This is the first study on freshwater fish assemblages from rivers flowing off from the western part of ERL. It is expected that the information would serve as a baseline knowledge for key authorities and stakeholders to conserve the biodiversity inhabiting freshwater ecosystems in Malaysia, and to promote conservation and management programs in the future.

Methods and materials

Study sites

Three rivers, Juaseh, Labis, and Segamat rivers, flowing off from the western part of the ERL, were assessed for their freshwater fish assemblages (Fig. 1). The average width and depth of Juaseh River was 8.51 meters and 0.4 meters respectively. It is estimated that the Juaseh River runs along approximately 29 km before joining the Segamat River. Similarly, the Segamat River with an average of 11.06 meters of width and 0.4 meters depth, originated from the ERJNP, flows approximately 45 km before joining with the Muar River at the west of the national park. For the Labis River, the dimensions are an average of 5.33 meters in width and depth ranged between 0.15–0.20 meters. The river starts from the hills of the Labis Forest Reserve, then flows to the south of the landscape complex before joining the Muar River. It is estimated that the Labis River runs more than 60-km before flowing into the Muar River.

Four substations were established in each river with a minimum of 3 km intervals between one substation and another. Each substation sampled its freshwater fish along a 200-meter long transect. All substations #1 were located at the headwater of each

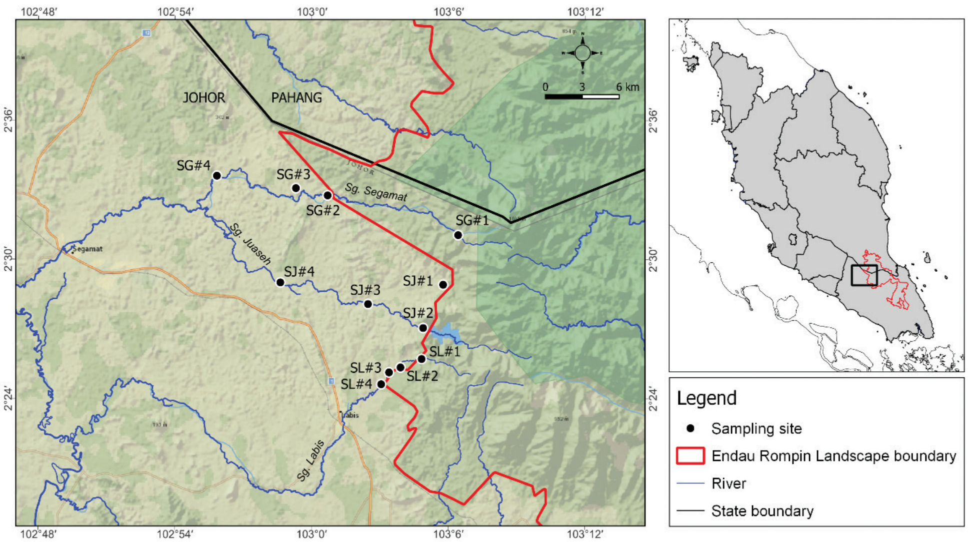

Figure 1. The localities of the 12 substations to study the composition and distribution between freshwater fish assemblages in three rivers in ERL.

river, where they were protected in the forest reserve, and the river's condition was pristine from any anthropogenic activities. The vegetation conditions in each substation #1 were dense with emerging trees, and the rivers were covered with close canopies. The soil substrates were mostly boulders with sandy banks. Some sites were designated as public recreation sites, such as waterfalls.

The subsequent substations #2, #3, and #4 of each river flowed through developed areas, including open land, shrubs, housing areas, and oil palm plantations. Largely, this section of the river was lightly polluted thanks to the presence of oil palm plantations or human settlements. The vegetation along the substation was mainly shrubs with algae submerged into riverbeds and was not covered by tree canopies. The boulders and cobbles were absent in these substations but were largely covered by sand, silt, and clay (Table 1).

Freshwater fish sampling

Fish samples were collected from 12 substations (Fig. 1) based on habitat representativeness and accessibility from September to November in the year 2021. Fish sampling in each substation was based on two approaches; electro-fishing and net scooping along the 200-m transect. The first group with a minimum of four persons were tasked with electro-fishing, while the second group conducted scooping using fine-sized scoop nets along the transect. A backpack Root-Smith LB24 electro-fisher unit was used to stun fish in each designated substation by applying a standardized voltage and current for an hour of effort. A single person operated the unit with assistance from three to four persons to collect the stunned fish using scoop nets. The second group was tasked with scooping out fish using fine-sized scoop nets from underneath wood debris, below riverbanks with hollows, sub-

Table 1. The locations and characteristics of substations established at the western part of ERL, Malaysia.

River	GPS coordinates	Width (m)	Depth (m)
Segamat River			
Substation #1	2°31'3.10"N, 103°6'25.91"E	14.57	0.51
Substation #2	2°32'45.56"N, 103°0'42.09"E	10.1	0.36
Substation #3	2°33'4.29"N, 102°59'18.55"E	7.15	0.41
Substation #4	2°33'36.19"N, 102°55'50.33"E	12.41	0.3
Juaseh River			
Substation #1	2°28'54.73"N, 103°5'46.44"E	8.53	0.43
Substation #2	2°27'2.69"N, 103°4'53.80"E	2.2	0.51
Substation #3	2°28'4.56"N, 103°2'28.65"E	10.44	0.32
Substation #4	2°29'0.38"N, 102°58'37.80"E	12.87	0.45
Labis River			
Substation #1	2°25'42.55"N, 103°4'49.99"E	5.96	0.2
Substation #2	2°25'20.63"N, 103°3'54.39"E	4.63	0.05
Substation #3	2°25'7.86"N, 103°3'24.16"E	2.77	0.27
Substation #4	2°24'37.16"N, 103°3'3.55"E	7.97	0.15

merged vegetation along the river, and any potential area within the river that was unreachable by the electro-fisher. Both approaches were conducted with an hour's effort of fishing. All the substations sampled its freshwater fish once throughout the sampling session.

The collected fish were temporarily kept in a pail filled with water before being brought back for examination. When possible, the fish were identified to species level and released back into the river. Those that were unpreserved in 10% formalin solution were taken back to the laboratory for examination. Apart from a voucher for identification, additional samples were collected, and tissues from the specimens were excised for molecular analysis. Identification was conducted according to Zakaria-Ismail et al. (2020). All fish specimens were deposited in the Zoological Collection of Forest Research Institute Malaysia (**FRIM**).

Statistical analysis

All the data recorded in the field were transferred into a master list in the Microsoft Excel software with additional information on the taxonomic order. Then, the data were sorted into respective substations, and specimens of each species were counted. Also, data on water quality at each substation were analyzed and presented in Suppl. material 1.

We defined the relative abundance as (RA), RA = (Number of individuals for species A/Total number of individuals) ×100%. Species diversity can be defined as the species richness in a certain area during a certain period. Hence, we constructed a comparison boxplot to show the differences in species richness among the investigated rivers.

In order to investigate the differences in fish composition between substations, we combined fish data from each substation into four different groups; namely group 1 which consists of all substations #1, group 2 with substations #2; group 3 comprised of substations #3 and group 4 with all substations #4. Analysis of non-metric multidimensional scaling (NMDS) was conducted to infer the fish composition using the metaMDS function in the R package vegan 2.5–3 (R Core Team, Vienna, Austria). We conducted a permutational analysis of variance (PERMANOVA) to compare the fish assemblages at each substation. Before PERMANOVA, the multivariate homogeneity of group dispersions was tested using the function betadisper, and there was no difference in dispersion between groups/substations (F = 0.63, ϱ = 0.61).

Results

Fish assemblage composition

In total, sixty-six freshwater fish species, including 841 specimens, were collected in the 12 substations of these three rivers (Juaseh, Labis, and Segamat) flowing off from the western part of the ERL, distributed in 43 genera, 18 families and six orders (Table 2). Among them, the most species-rich order was Cypriniformes (26 genera, seven families and 39 species), followed by the order Siluriformes (six genera, four families and 10 species). Anabantiformes and Synbranchiformes with three families comprise five genera of eight and five species, respectively. Order Gobiiformes only recorded a single family and a single genus and species.

Cyprinidae was the most dominant family, with 17 species, comprising 52% of the total abundance collected from all the substations (Table 1), followed by Danionidae and Cobitidae, with six species each. The families with the lowest number of species were Pristolepididae, Belonidae, Vaillantellidae, Siluridae, Eleotridae, and Synbranchidae, with a single species each.

Crossocheilus obscurus Tan & Kottelat, 2009 was the most abundant species collected in all the substations with a total of 85 collected specimens, followed by *Barbodes sellifer* Kottelat & Lim, 2021 and *Mystacoleucus obtusirostris* (Valenciennes, 1842), with 56 and 52 specimens, respectively. *Pangio malayana* (Tweedie, 1956), *Epalzeorhynchos kalopterum* (Bleeker, 1850), *Osteochilus microcephalus* (Valenciennes, 1842), *Nemacheilus selangoricus* Duncker, 1904, *Vaillantella maassi* Weber & de Beaufort, 1912, *Parachela oxygastroides* (Bleeker, 1852), and *Leiocassis micropogon* (Bleeker, 1852) were the species with singleton sample collected throughout the sampling session.

Fish composition among rivers and substations

Among the three rivers investigated, Segamat River recorded the highest species richness with 45 species, followed by Juaseh River with 36 species, and Labis River with 34 species of freshwater fishes. Among the investigated rivers, based on standardized effort, the highest number of specimens were captured in Segamat River (355 specimens), followed by Labis River (262 specimens), and the least was in Juaseh River (224 specimens) (Fig. 2).

The fish composition among the substations varied significantly. Substation #1 recorded 33 species, as the species richness increased in substation #2 (with 40 species) and substation #3 (41 species). However, the species richness recorded at substation #4 showed a marked reduction to 29 species compared to the other substations (Table 2). The fish compositions in substation #1 of the three rivers were grouped separately

Table 2. List of freshwater fish, relative abundance and originality that were collected from the three rivers flowing off western Endau-Rompin Landscape.

Species	Sg. Juaseh				Sg. Labis				Sg. Segamat				Relative Abundance (%)	Originality
	SJ1	SJ2	SJ3	SJ4	SL1	SL2	SL3	SL4	SG1	SG2	SG3	SG4		
Anabantiformes														
Channidae														
Channa limbata (Cuvier 1831)					3				2				0.59	Native
Channa lucius (Cuvier 1831)	1				1	3		1					0.71	Native
Channa melasoma (Bleeker, 1851)					7								0.83	Native
Channa striata (Bloch, 1793)			1									1	0.24	Native
Osphronemidae														
Betta pugnax (Cantor, 1849)					8	7	3						2.14	Native
Trichopodus trichopterus (Pallas, 1770)			1		1				1	1			0.48	Native
Trichopsis vittata (Cuvier, 1831)			4	2									0.71	Native
Pristolepididae														
Pristolepis grootii (Bleeker, 1852)		2	2	1									0.59	Native
Beloniformes														
Belonidae														
Xenentodon cancila (Hamilton, 1822)											1		0.12	Native
Zenarchopteridae														
Dermogenys collettei Meisner, 2001			3									2	0.59	Native
Hemirhamphodon pogonognathus (Bleeker, 1853)					16	5	8						3.45	Native
Cypriniformes														
Balitoridae														
Balitoropsis zollingeri (Bleeker, 1853)						1		1					0.24	Native
Homaloptera ogilviei Alfred, 1967									5	5	5		1.78	Native
Homaloptera parclitella Tan & Ng, 2005	5	2							4				1.31	Native
Homalopteroides tweediei (Herre, 1940)											6	2	0.95	Native
Pseudohomaloptera (Leonardi Hora, 1941)								2					0.24	Native
Cobitidae														
Acantopsis dialuzona Van Hasselt, 1823			3		1				1	8	5	1	2.26	Native
Aperioptus pictorius Richardson, 1848										1	1		0.24	Native
Pangio malayana (Tweedie, 1956)											1		0.12	Native
Pangio muraeniformis (de Beanfort, 1933)						3							0.36	Native
Pangio piperata Kottelat & Lim, 1993											2		0.24	Native
Pangio semicincta (Fraser-Brunner, 1940)			19										2.26	Native
Cyprinidae														
Barbodes lateristriga (Valenciennes, 1842)	2				8	8	6	1			1		3.09	Native
Barbodes sellifer (Kottelat & Lim, 2021)	9	4	3	2	17	5	9	3	2		1	3	6.9	Native
Crossocheilus obscurus Tan & Kottelat, 2009	3	21	1	2			2			55	1		10.11	Native
Crossochilus oblongus Kahl & Van Hasselt, 1823									20				2.38	Native
Cyclocheilichthys apogon (Valenciennes, 1842)			2	3									0.59	Native
Cyclocheilichthys armatus (Valenciennes, 1842)								1		2			0.36	Native
Epalzeorhynchos kalopterum (Bleeker, 1850)										1			0.12	Native
Hampala macrolepidota Kuhl & Van Hasselt, 1823	1	1					2	3		1			0.95	Native
Labiobarbus leptocheilus (Valenciennes, 1842)				12			3	2		12		6	4.16	Native
Lobocheilos rhabdoura (Fowler, 1934)	8	2							7	14	2		3.92	Native
Mystacoleucus obtusirostris (Valenciennes, 1842)	1	3	7	7						28	5	1	6.18	Native
Neolissochilus soroides (Duncker, 1904)	6								4				1.19	Native
Osteochilus microcephalus (Valenciennes, 1842)				1									0.12	Native
Osteochilus scapularis Fowler, 1939									7				0.83	Native
Osteochilus vittatus (Valenciennes, 1842)			2		1		7			6	3	5	2.85	Native
Osteochilus waandersii (Bleeker, 1853)	3			4	7	2	3	8	9	11		2	5.83	Native
Poropuntius normani Smith, 1931					5	6			11				2.62	Native
Danionidae														
Luciosoma setigerum (Valenciennes, 1842)											3		0.36	Native
Rasbora bankanensis (Bleeker, 1853)					10								1.19	Native
Rasbora elegans Volz, 1903	6	5	11	2	11	6	6			1			5.71	Native

Species	Sg. Juaseh				Sg. Labis				Sg. Segamat				Relative Abundance (%)	Originality
	SJ1	SJ2	SJ3	SJ4	SL1	SL2	SL3	SL4	SG1	SG2	SG3	SG4		
Rasbora myersi Brittan, 1954				3			1			1	2		0.83	Native
Rasbora paucisqualis Ahl, 1935						7			8		8		1.78	Native
Trigonostigma heteromorpha (Duncker, 1904)					12								1.43	Native
Nemacheilidae														
Nemacheilus paucimaculatus Bohlen & Šlechtová, 2011					1	1	1	3		11			2.02	Native
Nemacheilus selangoricus Duncker, 1904											1		0.12	Native
Vaillantellidae														
Vaillantella maassi Weber & de Beaufort, 1912										1			0.12	Native
Xenocyprididae														
Parachela oxygastroides (Bleeker, 1852)			1										0.12	Native
Oxygaster anomalura Van Hasselt, 1823											2		0.24	Native
Gobiiformes														
Eleotridae														
Oxyeleotris marmorata (Bleeker, 1852)			4										0.48	Native
Siluriformes														
Bagridae														
Leiocassis micropogon (Bleeker, 1852)										1			0.12	Native
Mystus castaneus Ng, 2002	2				2				2				0.71	Native
Mystus singaringan (Bleeker, 1846)		1	4										0.59	Native
Pseudomystus leiacanthus (Weber & de Beaufort, 1912)					1					2			0.36	Native
Clariidae														
Clarias batrachus (Linnaeus, 1758)			2			1							0.36	Native
Clarias leiacanthus Bleeker, 1851					3	2							0.59	Native
Siluridae														
Silurichthys hasseltii Bleeker 1858					2	1			1				0.48	Native
Sisoridae														
Glyptothorax fuscus Fowler, 1934	1							1	2	9		5	2.14	Native
Glyptothorax platypogonoides (Bleeker, 1855)						3					3		0.71	Native
Glyptothorax schmidti (Volz, 1904)	1				1								0.24	Native
Synbranchiformes														
Syngnathidae														
Doryichthys martensii (Peters, 1868)			9								4	2	1.78	Native
Doryichthys deokhatoides (Bleeker, 1854)				1						4	4		1.07	Native
Synbranchidae														
Monopterus javanensis Lacepede, 1800			1			2	3	1					0.83	Native
Mastacembelidae														
Macrognathus maculatus (Cuvier, 1832)	1								1	1		1	0.48	Native
Mastacembelus favus Hora 1924		11	1	1									1.55	Native

compared with other substations, as shown in the NMDS ordination (Fig. 3). The fish structure in substations #2, #3, and #4 overlapped.

Discussions

The fish assemblage presented in this study is the first insight into fish diversity found in the Juaseh, Segamat, and Labis Rivers, flowing off from the western part of the ERL. A total of 66 freshwater fish species were recorded in the three rivers, representing approximately 10% of freshwater fish diversity found in Malaysian territory. Fishes of the order Cypriniformes are the main freshwater inhabitants and contribute to almost

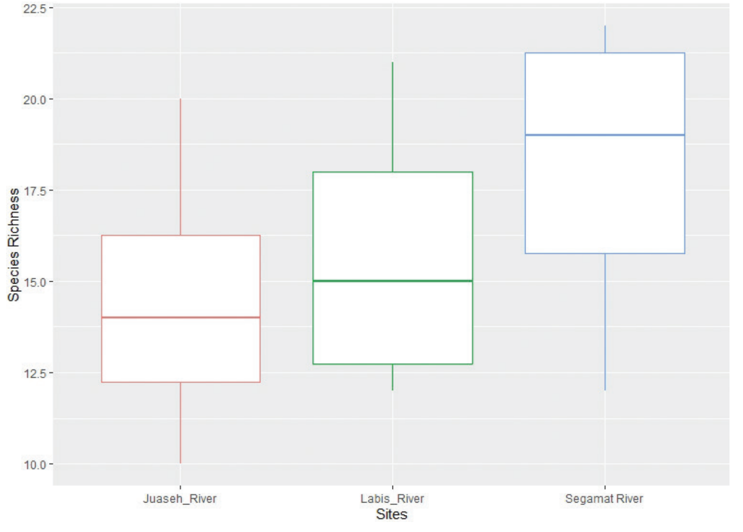

Figure 2. The boxplot shows the species richness of freshwater fish for all three investigated rivers in the western part of the Endau-Rompin Landscape.

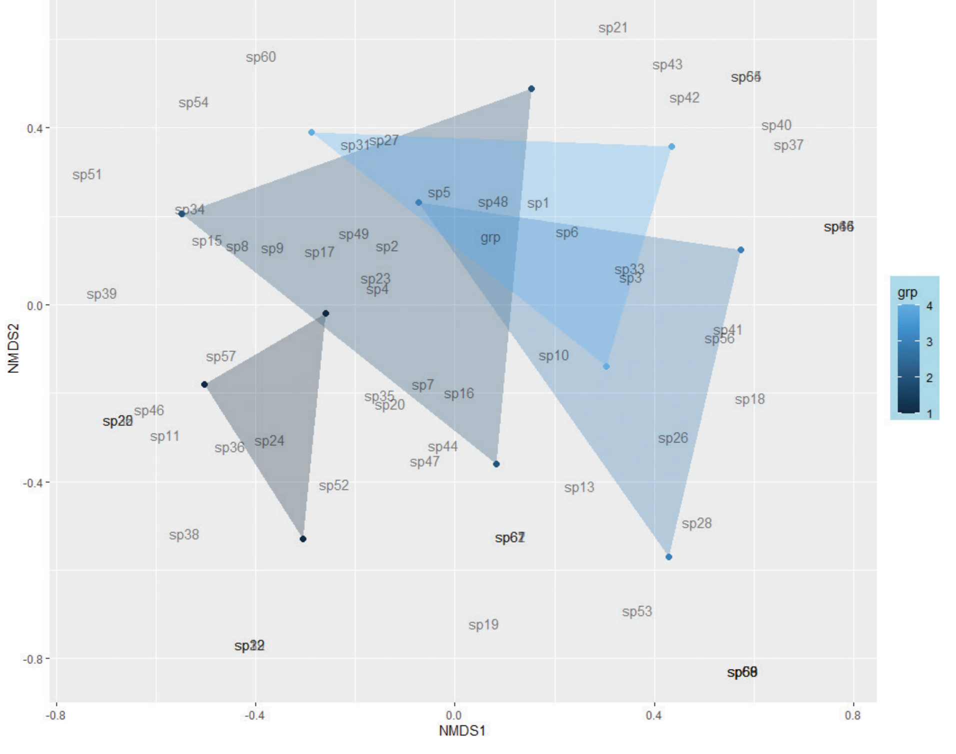

Figure 3. NMDS analysis for each substation examined along study areas. The composition of fish on substations #1 differs significantly from substations of #2, #3 and #4. Each convex hull represents Group 1 = substations #1, Group 2 = Substations 2, Group 3 = Substations #3 and Group 4 = Substations #4.

10% of all teleost species globally (Wood 2019). Most tropical freshwater fishes in Asia are dominated by Cypriniformes (barbs and loaches), Siluriformes (catfishes), anabantoids (gouramis, climbing perches, and snakeheads), and mastacembelids (spiny eels). In addition, several freshwater species come from estuaries or marine environments, such as: Beloniformes (halfbeaks and needlefish), Atheriniformes (silversides), Eleotridae (sleeper gobies), Gobiidae (goby), and Tetraodontidae (pufferfish) (Winemiller et al. 2008). Across the investigated rivers, the family Cyprinidae was dominant and accounted for almost half of the total catch. Dominance by the family Cyprinidae in tropical rivers is common due to their highly morphological adaptations (Ward-Campbell et al. 2005), wide distribution (Mohsin and Ambak 1983), and is supported by previous studies (Kaviarasu et al. 2013; Rashid et al. 2015; Ng et al. 2019, Soo et al. 2021) conducted in Peninsular Malaysia and Borneo.

Families, such as Belonidae, Vaillantellidae, and Eleotridae, were less sampled in this study. A similar result was reported in the Keniyam River, in National Park Taman Negara Pahang by Mohd-Azham and Singh (2019), with a low abundance of belonid species. The family Siluridae (silurid catfishes) have 17 species recorded in Peninsular Malaysia; however, this study only managed to capture four specimens of the species *Silurichthys hasseltii* Bleeker, 1858. Based on the documentation of freshwater fishes in Peninsular Malaysia by Zakaria-Ismail et al. (2019), most silurid species are rare and restricted to particular rivers in Peninsular Malaysia. This justifies the fact that species of this family usually present low abundance, and the chances of collecting species of silurid is extremely low.

Crossocheilus obscurus of the family Cyprinidae was the most abundant species among all three rivers in this study. This species was described by Tan and Kottelat (2009) from the middle of the Batang Hari drainage of Sumatra. The species has also been discovered in Malaysia, specifically in the Muar River of Johor and the Kampar River in Perak. Even though Zakaria-Ismail et al. (2019) confirmed that the species is uncommon in Peninsular Malaysia, our study was able to gather a sizable number of *C. obscurus* specimens from the Segamat and Juaseh Rivers (total specimens of 85). It could be a spawning ground for *C. obscurus* in the Juaseh and Segamat Rivers, as the abundance was high, and the species dominated several substations along both rivers. Also, habitat preferences for *C. obscurus* are related to fast-flowing streams with clear water and the bottom substrates of rocks and submerged logs. Such conditions were observed in the substations where the species were recorded, providing an optimum condition for its persistency. Conversely, most species that were collected in this study are low in abundance. However, these fishes were commonly present throughout Peninsular Malaysia (Zakaria-Ismail et al. 2019).

Fish species composition is marked by habitat heterogeneity, environmental gradients, and human activity (Sehr and Keckeis 2017; Shukla and Bhat 2017) at local and regional scales (Benke et al. 2011; Hasegawa et al. 2017; Nicol et al. 2017; Cheng et al. 2019). Comparably, the fish richness in this study increases across the substations following the river's gradient. Basically, substation #1 is located at the headwater of each river, whereas substations #2 and #3 are a feature of midstream, and substation

#4 is downstream. The fish assemblage reflects the gradual changes in structural and physicochemical properties from the upper to the lower reaches (Petry and Schulz 2006). A higher species richness was expected in substation #4 as the fish species richness progressed toward downstream (Horwitz 1978; Vannote et al. 1980), but surprisingly, fish assemblage was much lower. Such findings may contribute to land-use change and anthropogenic disturbance downstream (Benejam et al. 2016; Leitão et al. 2018). It was observed that the intensity of human settlement and agricultural activity downstream were significant compared to the upper reaches. Hence, the downstream fish composition was majorly dominated by highly tolerant species, and those species that had acquired cleaner and pristine habitats were absent. Such a suggestion was supported by the NMDS ordination result of this study. The convex hull grouped substations according to the fish composition, which resulted in substation #1 being separated from the other substations. Such results indicated that different species were present exclusively in substation #1 and absent from other substations.

Conservation of fish in the ERL and recommendations

The community's major economy in the study area is oil palm plantations and agricultural estates. The current land-use changes in the study areas, which humans mainly cause, would directly impact negatively on freshwater fish communities. It was suggested that any form of logging activity, including selective logging, widely practiced by foresters, could create a positive ecosystem for freshwater fish (Iwata et al. 2003; Wilkinson et al. 2018). Although there was no significant difference in fish diversity between logged forest and oil palm catchments in the Sabah River reported by Wilkinson et al. (2018), the forests can be constructive and influence the diversity of freshwater fish communities by increasing the heterogeneity in physical structures and food materials in freshwater habitats (Lo et al. 2020). The anthropogenic land cover change could also serve to increase the sedimentation, changes in water pH, and the availability of food materials that directly influence the number of aquatic organisms (Lo et al. 2020). Consequently, the understanding of habitat alteration, especially between forest and aquatic ecosystems, should be enhanced to provide a systematic framework for conservation programs.

Disturbances in the riparian zone along the rivers could have harmful impacts on the terrestrial communities and indirectly affect the freshwater ecosystem (Grimm et al. 2008; Vörösmarty et al. 2010). Riparian zones are the landscapes that form an interface between terrestrial and aquatic ecosystems, with disproportionate influences on the dynamics of the food web and the function of the ecosystem in both habitats. The plant communities along the riverbanks and margins are known as riparian vegetation. They are very significant for fish communities, as they influence light regimes, water quality, thermal dynamics, habitat, and food availability. The riparian buffer along Juaseh, Segamat, and Labis rivers, especially downstream, was not clearly visible as most zones were destroyed or encroached by human activities. The loss of riparian vegetation situated along these rivers could eradicate the food sources and breeding areas of the fish communities. A successful idea of adapting buffer zones has been reviewed in India, where the program, Freshwater Fish Safe Zone, has effectively aided in freshwater fish conservation (Gupta et al. 2014). Therefore, safeguarding the network of the river-riparian zone would be essential in rehabilitating the degraded habitats, which resulted from the urbanization (Coelho et al. 2014).

Freshwater fishes are important sources of protein to the rural communities that live in the inland and riverine rural areas. However, many freshwater fishes in Malaysia have been overharvested, especially the large-sized and game fishes, including Mahseer and *Probarbus jullieni* Sauvage, 1880 (Chong et al. 2010). Overharvesting mostly occurred in habitats that lack surveillance, which could lead to the decreasing number of freshwater fishes or extinction of the species in the wild. For certain species, such as Betta, it is believed to be overharvested due to trading for the ornamental industry since Betta is very famous and has always been a popular preference among ornamental fish enthusiasts because of its color and shape in Malaysia. Therefore, relevant authorities should take proactive measures in curbing overharvesting by enforcing, monitoring, and guarding the natural habitats besides introducing seasonal harvesting, which could assist in maintaining the wild population of freshwater fish.

The establishment of policies or management plans for the freshwater ecosystem is a matter of requirement, but enforcement could be more crucial. Even though several conservation policies have been put in place in Malaysia for many years, the government continues to poorly manage most of the ecosystems due to the lack of stakeholder participation, inefficient conservation programs, and failure to raise community awareness (Abdullah et al. 2014). Engagement by pertinent stakeholders and authorities should be more holistic and covered by all layers of administration. In this study, the relevant authorities responsible for freshwater fish and ecosystem rely on the Department of Fisheries, State Forestry Department, and the district official since the rivers transcend multi-jurisdictions. These authorities should be advised based on scientific facts to help them design, develop, and execute any rehabilitation effort within their jurisdiction. The involvement of local communities is crucial in ensuring that any conservation and management plan in place is successful. According to Rampheri and Dube (2020), local communities play an essential role in executing management plans since most locals have extensive knowledge and experience in managing and conserving natural resources while safeguarding their livelihoods. The local community should be further informed on nature and its benefits that will likely influence their lives and improve their awareness of conserving the surrounding ecosystems. The scientific society in Malaysia should be more engaging in conserving the freshwater ecosystem by conducting in-depth research, especially on long-term monitoring. The relationship between species and the ecosystem is complex, and the diversity of monitoring requirements must be considered and combined (Deines et al. 2017; Allison and Mills 2018). The conservation measures should be evidence-based to implement the best strategy to protect and rehabilitate the existing ecosystems within the country.

Conclusion

The knowledge presented here is the first documentation on the freshwater fish from the Juaseh, Labis, and Segamat rivers in Malaysia. The diversity and composition of fish species in these rivers differed suggestively, and the distribution along the river gradient changes gradually from the headwater to downstream. The information would serve as a baseline information for key authorities and stakeholders to preserve and conserve the biodiversity inhabiting freshwater ecosystems in Malaysia, in a sustainable management manner.

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Supplementary material 1

Eleven environmental variables measured in each substation of rivers Juaseh, Segamat, and Labis of ERL.

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