Journal of Oil Palm Research
DOI: https://doi.org/10.21894/jopr.2022.0077

FISH SPECIES RICHNESS, THEIR IMPORTANCE AND CONSERVATION STATUS IN TROPICAL OIL PALM AGROECOSYSTEM OF TERENGGANU, PENINSULAR MALAYSIA

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ABSTRACT

Oil palm cultivation is expanding especially in Malaysia, where natural land occupied by small streams and rivers has been converted into an agroecosystem. This study assessed and estimated fish species richness and fish diversity in the tropical oil palm plantation in Terengganu, Peninsular Malaysia, along with their importance, and conservation status. From 57 fish species recorded, 28 species were suitable as ornamentals, 21 species for both food and ornamentals, and four species were considered suitable as ornamentals, food, and sport fishing. About 54 fish species were classified in the Least Concern (LC) category while one species each was classified in the Data Deficient (DD) and Not Evaluated (NE) categories. More species can be recorded by increasing the sampling efforts as suggested by Chao 1 species richness estimator. Tributary Sungai Nerus has the highest fish species diversity and species richness, while Sungai Jeneris has the lowest fish species diversity, species richness, and species evenness. Continuous data collection can determine the true fish species richness and fish diversity in the oil palm plantation, which can help to suggest good management schemes to conserve fish fauna in this agroecosystem.

Keywords: agroecosystem, conservation, fish diversity, freshwater fish, sustainable.

Received: 10 April 2022**; Accepted:** 18 October 2022**; Published online:** 13 December 2022.

INTRODUCTION

The effect of land changes on organisms can vary; the species richness can decrease (Wilkinson *et al*., 2018), increase (Lorion and Kennedy, 2009) or be unaltered (Bojsen and Barriga, 2002). Land use has been criticised due to the rapid expansion which had caused habitat destruction and subsequent loss of biodiversity (Immerzeel *et al*., 2014). It had altered the habitat structure of the rivers and streams (Ferreira *et al*., 2018) through soil erosion and led to pesticide run-off into the water bodies. This will subsequently affect the aquatic organism in their microhabitat especially fish (Wilkinson *et al*., 2018). The impact of land conversion is irreversible (Dislich *et al*., 2017; Moreno-Mateos *et al*., 2012) but can be reduced to sustain the survival of multi-diverse flora and fauna.

To our knowledge, a specific study on fish diversity in freshwater streams associated with oil palm monoculture plantations in Peninsular Malaysia has never been reported before. In the eastern part of Peninsular Malaysia, specifically in the state of Terengganu, most of the oil palm plantation areas reside in the adjacent forest/forest reserves and peatlands (Shevade and Loboda, 2019). In total, 171 548 ha of land in Terengganu were used for oil palm plantations until 2017 (Census and Economic Information Centre, 2020).

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Terengganu state has been chosen as the study site since Terengganu itself is very unique and ichthyo-diverse, as 11 new species of freshwater fishes were previously described for the first time (type locality) from its river systems and water-bodies, namely *Brevibora cheeya*, *Rasbora notura*, *Pangio alcoides*, *Pangio filinaris*, *Pangio piperata*, *Homaloptera parclitella*, *Amblyceps foratum*, *Akysis hendricksonii*, *Nanobagrus lemniscatus*, *Betta stigmosa*, and *Parosphromenus paludicola* (Kottelat, 2013). The list goes on with the description of the new species of other animals, such as crabs (Ng, 2020; Ng and Ahmad, 2016) and reptiles (Grismer *et al*., 2018; Sumarli *et al*., 2016). The trends show that there are chances of getting more species if more surveys were done in the selected area in Terengganu. Terengganu state also supported 103.67 t of inland fisheries landing worth USD554.81 (excluding dams) in 2019 (Department of Fisheries, 2020). The inland fisheries from the rivers in Terengganu are dominated by the catfish from the genus *Hemibagrus* sp., with the highest retail values (based on the total catches), followed by *Barbonymus schwanefeldii*, *Tor tambra*, and *Neolissochilus soroides* while other freshwater fish species were utilised at a smaller scale (Department of Fisheries, 2020).

In this study, we asked three research questions with regard to fish diversity in the oil palm plantation; 1) The total fish species richness and estimated fish species, 2) The conservation status and the importance of fish species, and 3) The significance of fish diversity among the streams and rivers. Despite having many small streams in the oil palm plantation, fish diversity and fish species richness in the streams within the plantations are rarely studied. It is partially unknown whether the fish community can fully adapt to such land modifications and frequent disturbances. This study is crucial for the management and conservation of aquatic resources in the tropical agroecosystem, and for the community's livelihood which depends on freshwater fishes for food and economic enhancement.

MATERIALS AND METHODS

Study Areas

The study was carried out at nine selected streams in oil palm plantations in Terengganu. All streams are freshwater streams but Sg. Ular (Sg. = Sungai, means river) which is a blackwater stream (peatland) (*Figure 1*). The majority of the streams are dominated by sandy bottom substrate, with slow to moderate water flow. All the streams sampled in this study were approximately 4-5 m wide, and the water depth were below 1.0 m. All the streams, except Sg. Ular, resides in the catchment area of Sungai Terengganu, with a size of 4560 km^2 which spans across three districts; Kuala Terengganu, Hulu Terengganu, and Setiu (Department of Irrigation and Drainage, 2015). Fish data collection sites were chosen haphazardly, in the middle reach of the stream based on the site accessibility. The haphazard sampling method is commonly used by ecologists, where the sampling sites were chosen opportunistically depending on the habitats and time (Andrew and Mapstone, 1987), while the target habitat is either remote, poorly studied, or in the underwater environments (Smith *et al*., 2017). The Sg. Ular blackwater stream originated from the peatlands area in Tasik Berombak, and flows through a peat swamp forest and oil palm plantations before being discharged into the lagoon of Setiu wetland.

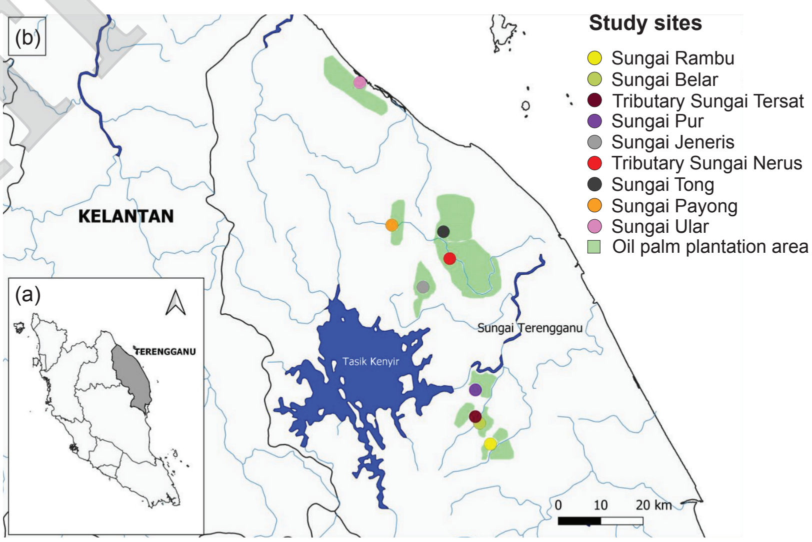

Figure 1. (a) The map of Terengganu located in the eastern part of Peninsular Malaysia, and (b) the study sites comprise of nine streams within the oil palm plantations in Terengganu.

Data collections

Samplings were conducted from June 2018 to December 2018. The electrofishing technique was done using a backpack electrofisher model LR-24 (Smith Roots Inc.) by wading in an upstream direction. There were three plots (every 30 m interval for each plot), sampled along 90 m reach of each stream. The distance for the sampling plots was determined as suggested by Patton *et al*. (2000) and Dauwalter and Pert (2003), for a minimum of 50 m length. The seine net was handled by two people; holding at the edge of both sides of the seine net to form a U-shape, to block fishes which drifted in the fast-flowing water current. Long-handled scoop nets were used to retain and catch the stunned fish. Fishes caught in the seine net were carefully removed and placed in a plastic basket immersed in flowing water, to reduce fish mortality. We used the electrofishing techniques in this study to maximise the sampling efforts, as it is more effective than the single hand-seining methods in tropical streams (Deacon *et al*., 2017).

Fish Identification and Preservation

The fishes were first euthanized in tricaine methanesulfonate (MS-222) before being identified *in situ*. The voucher specimens (one to three individuals for each species) were taken for further confirmation of the species' identity. The fishes were identified according to the taxonomic keys following Zakaria-Ismail *et al*. (2019) and verified based on Fricke *et al*. (2022). The specimens were preserved in 10% formalin for at least two weeks. The specimens were then immersed in tap water to remove the fixative and preserved in 70% of ethanol solution for long-term preservation. The preserved fishes are kept in the General Biology Laboratory of Universiti Malaysia Terengganu Zoological Collections (UMTZC). The IUCN Status for all fish species identified were based on The IUCN Red List of Threatened Species version 2021-3, while the guidelines for "Uses" were referred primarily based on The IUCN Red List of Threatened Species version 2021-3, under General Use and Trade Classification Scheme (Version 1.0).

Statistical Analysis

Species accumulation curves (SAC) were plotted into two types of curves (abundance-based; the total number of individuals and sample-based; the number of streams) to determine the sampling completeness. The species richness estimator, Chao 1 was also employed to compare the observed species richness (S_{obs}) and estimated species richness (S_{est}) for all streams. There were six diversity indices used to measure fish diversity namely Shannon (H) and Simpson (1-D) for species diversity; Margalef (R1) and Menhinick (R2) for species richness; Equitability (EH) and Evenness (E) for species evenness. A diversity t-test was performed via a pairwise comparison between all streams to determine the significant difference in diversity, based on Shannon (H) and Simpson (1-D) values. We chose both indices as it measures the diversity based on two main components of species diversity; species richness and species evenness (Gorelick, 2006), while the other indices used in this study only measure species richness (R1 and R2), and species evenness (EH and E) (Magurran, 2004). All the statistical analyses were done using Paleontological Statistics Software (PAST version 4.03) (Hammer *et al*., 2001).

RESULTS

A total of 57 species of freshwater fish species from 20 families was recorded from nine streams in oil palm plantations in Terengganu, Peninsular Malaysia (*Table 1*). The family Cyprinidae was the most dominant family with the highest species richness (15 species) followed by the family Danionidae, Balitoridae, and Bagridae with five species respectively. The family Cobitidae has four species, followed by Channidae (three species), while the families Nemacheilidae, Akysidae, Zenarchopteridae, Mastacembelidae, Gobiidae, Osphronemidae has two species. Other families were represented by single species only. Among all streams, Sg. Tong has the highest number of species (18 species), followed by Sg. Pur, Sg. Payong and Tributary Sg. Nerus (17 species each), Sg. Rambu (16 species), Sg. Tersat (15 species), Sg. Ular (13 species), Sg. Belar (11 species) and Sg. Jeneris (9 species) (*Table 1; Figure 2*). Based on The IUCN Red List of Threatened Species version 2021-3, the majority of the species was in the Least Concern (LC) categories (96%; 54 species), followed by Not Evaluated (NE) (2%; 1 species), Data Deficient (DD) (2%; 1 species). One species was not assessed as it could be an undescribed species (*Rasbora* cf. *notura*). About 28 fish species were regarded as ornamental fishes (*i.e., Nemacheilus masyae*, *Homaloptera parclitella*, and *Rasbora paucisqualis*), while 21 species were utilised for both food and ornamental purposes (*i.e., Acantopsis dialuzona*, *Ceratogarra cambodgiensis*, *Mastacembelus favus*). Three species were used as food only (*Hemibagrus capitulum*, *H. gracilis*, and *Monopterus javanensis*), one species was used as food and for sport fishing (*Channa striata*), while four species have all three importance as food, ornamental, and for sport fishing (*Channa lucius*, *C. melasoma*, *Hampala macrolepidota*, and *Neolissochilus soroides*) (*Table 1*).

TABLE 1. FISH SPECIES LIST RECORDED IN OIL PALM STREAMS IN TERENGGANU, PENINSULAR MALAYSIA

Family and species	Sg. Rambu	Sg. Belar	Tributary Sg. Tersat	Sg. Pur	Sg. Jeneris	Tributary Sg. Nerus	Sg. Tong	Sg. Payong	Sg. Ular	IUCN status (2021-3)	Uses
Notopteridae											
Notopterus notopterus	-	-	-	-	-	-	-	-	+	LC	F, O
Cobitidae											
Acantopsis dialuzona	-	+	-	+	+	+	+	-	-	LC	F, O
Acanthopsoides molobrion	-	-	-	+	+	-	+	-	-	LC	O
Pangio doriae	-	-	-	-	-	+	-	-	-	LC	O
Pangio semicincta	-	-	-	-	-	-	+	-	-	LC	O
Balitoridae											
Balitoropsis zollingeri	+	+	-	-	-	+	-	+	-	LC	O
Homaloptera ogilviei	-	+	-	-	-	-	-	+	-	LC	O
Homaloptera parclitella	-	-	-	+	-	-	-	+	-	LC	O
Homalopteroides nebulosus	-	-	-	+	-	+	+	-	-	LC	O
Homalopteroides tweediei	+	-	-	-	-	-	-	-	-	LC	O
Nemacheilidae											
Nemacheilus masyae	-	+	-	-	+	+	+	-	-	LC	O
Nemacheilus selangoricus	-	-	+	-	-	-	-	-	-	LC	O
Cyprinidae											
Barbodes sellifer	+	+	+	+	-	+	-	+	-	LC	F, O
Barbodes cf. *binotatus*	-	-	-	-	-	-	-	-	+	LC	F, O
Barbodes lateristriga	+	-	+	+	-	-	-	-	-	LC	F, O
Crossocheilus oblongus	-	-	-	-	-	-	-	+	-	LC	O
Cyclocheilichthys apogon	-	-	+	-	-	-	-	-	-	LC	F
Ceratogarra cambodgiensis	+	-	-	-	-	+	-	+	-	LC	F, O
Hampala macrolepidota	-	-	-	-	-	-	+		-	LC	F, S
Labiobarbus leptocheilus	-	-	-	-	-	-	+	+	-	LC	F
Lobocheilos rhabdoura	-	-	-	-	-	-	-	+	-	LC	F
Mystacoleucus obtusirostris	-	-	-	+	-	+	-	-	-	LC	F, O
Neolissochilus soroides	+	-	-	-	-	-	-	-	-	LC	F, S
Osteochilus vittatus	-	+	-	-	-	-	+	+	+	LC	F, O
Osteochilus waandersii	+	+	-	-	-	-	+	+	-	LC	F, O
Poropuntius normani	+	-	-	-	-	+	-	-	-	LC	F, O
Puntigrus partipentazona	-	-	-	-	-	-	-	-	+	LC	O

TABLE 1. FISH SPECIES LIST RECORDED IN OIL PALM STREAMS IN TERENGGANU, PENINSULAR MALAYSIA (continued)

Family and species	Sg. Rambu	Sg. Belar	Tributary Sg. Tersat	Sg. Pur	Sg. Jeneris	Tributary Sg. Nerus	Sg. Tong	Sg. Payong	Sg. Ular	IUCN status (2021-3)	Uses
Danionidae											
Rasbora cf. *notura*	-	-	+	+	-	-	-	-	-	-	-
Rasbora myersi	+	-	+	-	+	-	+	+	-	NE	O
Rasbora notura	+	+	+	+	-	+	+	-	-	LC	O
Rasbora paucisqualis	-	-	-	+	-	-	-	-	-	LC	O
Rasbora paviana	-	-	-	-	-	-	-	-	+	LC	O
Bagridae											
Hemibagrus capitulum	-	+	+	-	-	-	+	-	+	LC	F
Hemibagrus gracilis	+	-	-	-	-	+	-	-	-	LC	F
Leiocassis poeciloptera	+	-	-	-	+	+	-	+	-	LC	O
Mystus castaneus	-	-	+	-	-	-	-	-	-	LC	F, O
Pseudomystus stenomus	-	-	-	-	+	-	-	-	-	LC	O
Akysidae											
Acrochordonichthys rugosus	-	-	-	-	+	-	-	-	-	LC	O
Akysis hendricksoni	-	-	-	-	+	-	-	-	-	LC	O
Amblycipitidae											
Amblyceps foratum	+	-	-	-	-	+	-	-	-	LC	O
Sisoridae											
Glyptothorax fuscus	+	+	+	+	+	+	-	+	-	LC	O
Siluridae											
Silurichthys schneideri	-	-	-	-	-	-	-	+	-	LC	F, O
Syngnathidae											
Doryichthys martensii	-	-	+	+	-	+	-	+	-	DD	O
Gobiidae											
Glossogobius giuris	-	-	-	-	-	-	-	-	+	LC	F, O
Pseudogobiopsis oligactis	-	-	-	-	-	-	-	-	+	LC	O
Mastacembelidae											
Macrognathus circumcinctus	+	-	+	+	-	+	-	+	-	LC	F, O
Mastacembelus favus	-	-	-	+	-	-	-	+	-	LC	F, O
Synbranchidae											
Monopterus javanensis	-	+	+	-	-	-	+	-	-	LC	F

TABLE 1. FISH SPECIES LIST RECORDED IN OIL PALM STREAMS IN TERENGGANU, PENINSULAR MALAYSIA (continued)

Family and species	Sg. Rambu	Sg. Belar	Tributary Sg. Tersat	Sg. Pur	Sg. Jeneris	Tributary Sg. Nerus	Sg. Tong	Sg. Payong	Sg. Ular	IUCN status (2021-3)	Uses
Osphronemidae											
Trichopodus trichopterus	-	-	-	-	-	-	+	-	-	LC	F, O
Trichopsis vittata	-	-	-	-	-	-	+	-	+	LC	O
Channidae											
Channa lucius	+	-	+	+	-	-	-	-	+	LC	F, O, S
Channa melasoma	-	-	-	+	-	-	-	-	-	LC	F, O, S
Channa striata	-	-	-	-	-	-	+	-	+	LC	F, S
Pristolepididae											
Pristolepis grootii	-	-	-	-	-	-	+	-	+	LC	F, O
Aplocheilidae											
Aplocheilus armatus	-	-	-	-	-	-	-	-	+	LC	O
Zenarchopteridae											
Dermogenys collettei	-	-	-	-	-	-	+	-	-	LC	O
Hemirhamphodon pogonognathus	-	-	+	+	-	+	-	-	-	LC	O
Total species	16	11	15	17	9	17	18	17	13		

Note: The IUCN status abbreviations are as follows: LC - least concern; DD - data deficient; NE - not evaluated.
F - food; O - ornamental; S - sport fishing; '+' - present; '-' - absence.

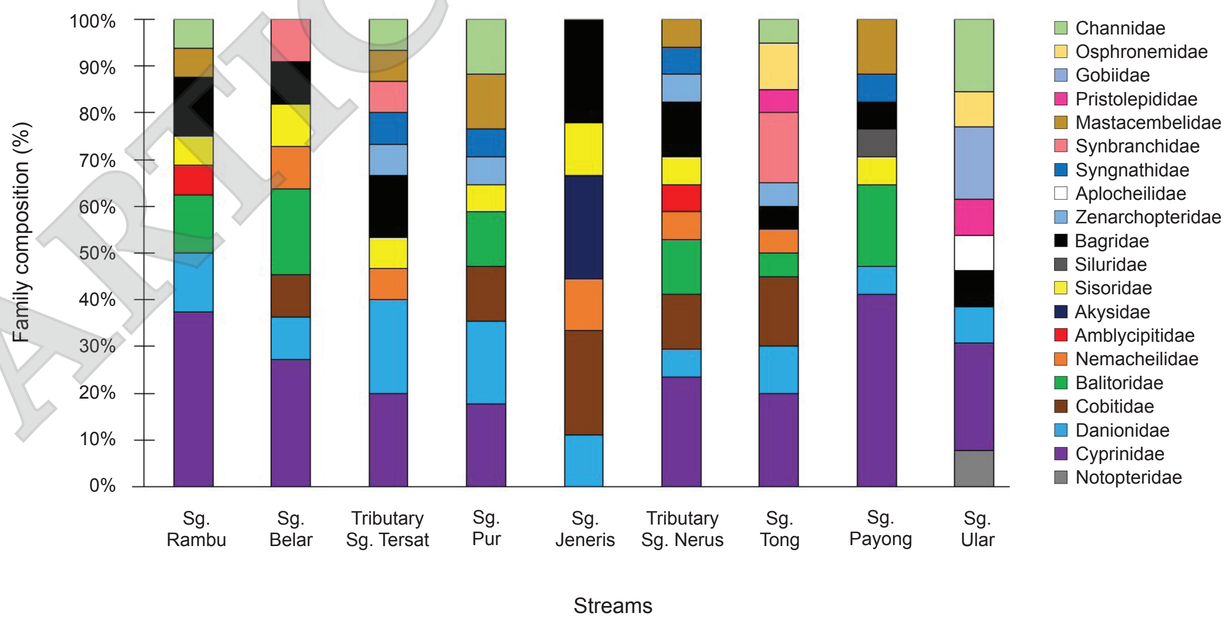

Figure 2. Family composition of freshwater fishes in nine streams in the oil palm plantation areas in Terengganu.

The species accumulation curves for both total abundance and stream numbers show no sign of reaching asymptotes based on the current sampling efforts (*Figures 3a; 3b*). The curves were steadily increasing, indicating that the sampling is not completed yet and more species may be added with the addition of sampling efforts (number of individuals and the number of streams). Plus, the species richness estimator, Chao 1 estimated more species than the observed species in each stream (*Figure 3c*).

The tributary of Sg. Nerus has shown the highest diversity indices value among all the streams except for Equitability and Evenness values, in which Sg. Belar has the highest Equitability and Evenness indices value, meanwhile Sg. Jeneris has shown the lowest diversity values for all indices among all the streams (*Table 2*). The diversity comparison showed no regular patterns in the significant difference of Shannon and Simpson values, except for Tributary Sg. Nerus and Sg. Jeneris, has a significant difference in Shannon and Simpson values with the other eight streams (*Table 3*).

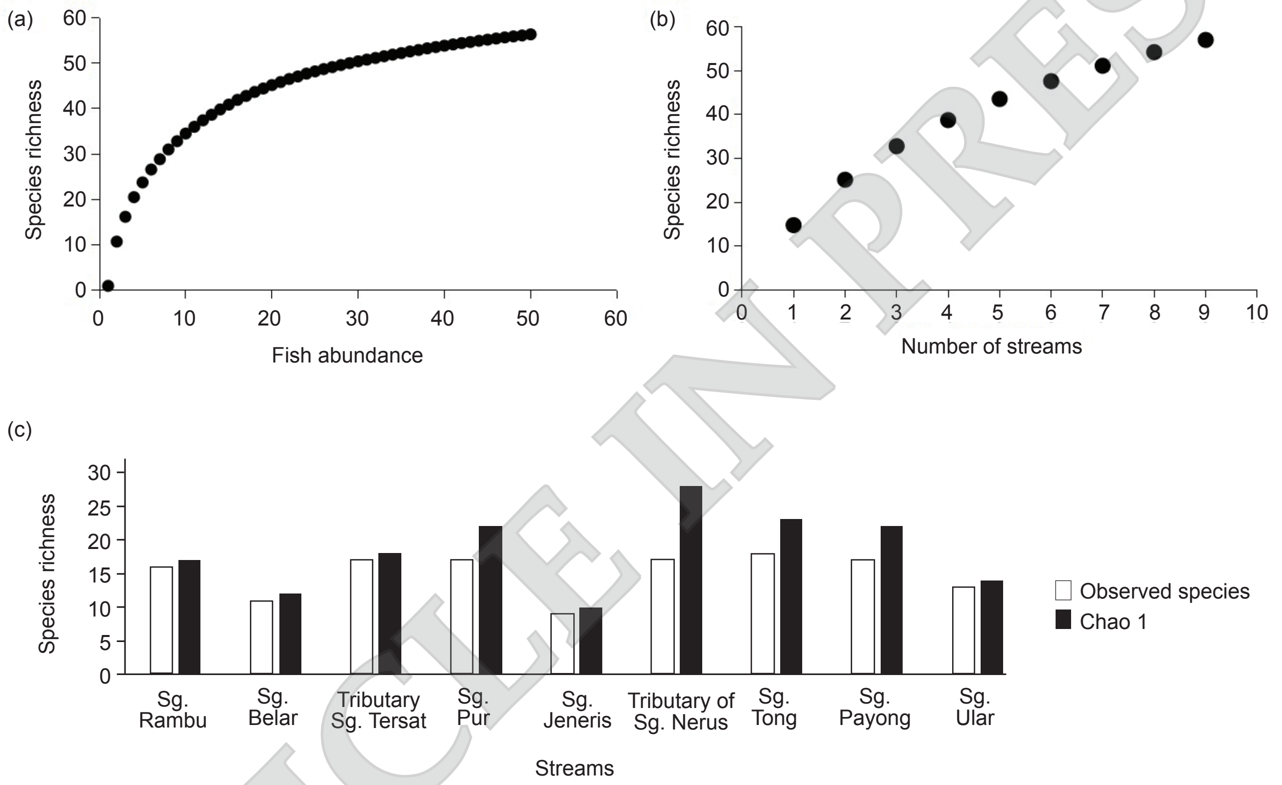

Figure 3. (a) Species accumulation curves for abundance and, (b) sample-based. (c) The estimated species richness by the estimator, Chao 1 also included for all streams.

TABLE 2. THE DIVERSITY VALUES IN NINE STREAMS IN THE OIL PALM PLANTATIONS

	Sg. Rambu	Sg. Belar	T. Sg. Nerus	Sg. Jeneris	Sg. Tong	Sg. Payong	Sg. Ular	T. Sg. Tersat	Sg. Pur
Shannon	2.031	2.167	**2.511	*1.378	2.163	2.344	2.054	2.253	2.307
Simpson	0.794	0.868	**0.901	*0.638	0.823	0.848	0.821	0.862	0.864
Margalef	3.067	2.659	**3.877	*1.903	3.842	4.156	2.955	3.213	3.662
Menhinik	1.387	1.677	**2.159	*1.100	1.567	2.480	1.707	1.698	1.913
Equitability	0.732	**0.904	0.886	*0.627	0.748	0.827	0.801	0.832	0.814
Evenness	0.476	**0.794	0.725	*0.441	0.483	0.6132	0.600	0.634	0.591

Note: '*' - the lowest diversity values while '**' - the highest diversity values. (Sg. = Sungai, T = Tributary).

TABLE 3. THE DIVERSITY COMPARISON BETWEEN NINE STREAMS USING SHANNON VALUES (H′) AND SIMPSON VALUES (1-D)

		Shannon values (H′)								
	Streams	**Sg. Rambu**	**Sg. Belar**	**T. Sg. Nerus**	**Sg. Jeneris**	**Sg. Tong**	**Sg. Payong**	**Sg. Ular**	**T. Sg. Tersat**	**Sg. Pur**
Simpson Index (1-D)	Sg. Rambu			Sig	Sig					
	Sg. Belar				Sig					
	T. Sg. Nerus	Sig			Sig			Sig		
	Sg. Jeneris	Sig	Sig	Sig		Sig	Sig	Sig	Sig	Sig
	Sg. Tong			Sig	Sig					
	Sg. Payong			Sig	Sig					
	Sg. Ular		Sig	Sig	Sig					
	T. Sg. Tersat	Sig			Sig	Sig		Sig		
	Sg. Pur	Sig		Sig	Sig	Sig		Sig		

Note: Only significant different comparisons were shown to increase the clarity of the table. (Sg. = Sungai, T = Tributary).

DISCUSSION

The current findings show that the family Cyprinidae and Danionidae make up the major family composition in this agroecosystem. This result is akin to the other studies on the agricultural landscape such as rice fields (Aqmal-Naser and Ahmad, 2018a; 2018b) and other plantation-related habitats (Ahmad *et al.*, 2018; Aqmal-Naser and Ahmad, 2021). It is historically well-known that Cyprinidae is the dominant family in the freshwater ecosystems in Peninsular Malaysia (Zakaria-Ismail *et al*., 2019), hence its dominance is not surprising. The total number of species richness, however, contributed to a small portion (19.72%) of the total 289 species of freshwater fishes recorded in Peninsular Malaysia (Zakaria-Ismail *et al*., 2019).

Almost all of the species were in the LC category and did not face any immediate threats, widespread (for certain species) and abundant in other places. The absence of rules and regulations regarding the over-exploitation of fish from wild sources, becomes a concern, especially for the fishes with higher ornamental values. More strict rules and regulations need to be implemented in Malaysia to avoid the over-collection of ornamental fish. The Brazilian government has introduced a ban on the export of the highly-sought fish species of the genus *Hypancistrus* (Isbrücker and Nijssen, 1991) to sustain the long-term sustainability of wild-capture fisheries (Pedersen, 2016). In addition, one species, *Hypancistrus zebra* has been prohibited to be collected, transported or traded in Brazil's aquarium fish trade as it was placed on the Brazilian Red List of Endangered species in 2004 (Evers *et al*., 2019). In Peninsular Malaysia, more studies are needed on the biology and ecology aspects of its fish species (*i.e.*, for species in the DD and NE categories) for proper long-term management of fisheries resources.

Species diversity, species richness and species evenness indices values for the fishes among the streams varied but the tributary of Sg. Nerus shows the highest diversity values but with low evenness. The species richness in the river is higher but the number of individuals (abundance) for each species is not uniform and shows dominancy by certain species. Meanwhile, Sg. Belar which shows the highest evenness value indicated that fish abundance for each species in the river can be considered uniform. Sg. Jeneris shows the lower diversity values but the highest evenness values, which means that the species richness was the lowest but with an approximately uniform number of individuals for each species. Besides, Sg. Jeneris also show a significant difference in species diversity to the lowest number of species richness compared to other streams. The result is aligned with the estimated number of species richness for a tributary of Sg. Nerus, which suggested more species could be recorded with additional sampling efforts (*Figure 3c*). Fish diversity was affected by various types of disturbances including habitat fragmentation (Poulet, 2007), habitat alteration (Holcik, 2003) and the expansion of agriculture that led to the absence of riparian zone (Wilkinson *et al*., 2018). The repetitive sampling approach (three times sampling visits) was recommended for more confident detection of the species richness of fishes in the streams (Reid and Haxton, 2017). Furthermore, future studies should consider the effect of longitudinal profiles of the stream corridor (upper stream, middle stream, and downstream), and the intensity of oil palm coverage toward fish diversity.

The ornamental fish sector in Malaysia has a prodigious market value. The sector is worth USD125 451 520.82 (RM506 447 789.55) in 2019, while Terengganu contributes about USD388 865.20 (RM1 569 848.80) to the ornamental fish values in

Malaysia (Department of Fisheries, 2020). However, the practice of aquarium dumping especially from the ornamental fish species has allowed the establishment of invasive alien species in the natural water bodies (Aqmal-Naser and Ahmad, 2020a). Luckily, no alien fish species were recorded in the study sites, suggesting that the habitat may not be suitable for alien species, or not yet been invaded. Precaution steps are needed by monitoring the presence of alien species before it is too late for eradication.

One small-sized species was not assessed and was identified as *Rasbora* cf. *notura*. The specimen resembles the holotype of *Rasbora notura* described by Kottelat (2005) but differs by its subdorsal blotch (SDB) and snout (*Figure 4*). Both *Rasboras* have similar general morphologies and a diamond-shaped blotch at the caudal peduncles. However, the real *R. notura* has a wider anterior subdorsal portion than the posterior part (Lumbantobing, 2014), while the second example has tapered and almost the same thickness of SDB, thus it does not fit into the description by Kottelat (2005) and Lumbantobing (2014) for the characteristic of *R. notura*. In addition, the snout of *R. notura* is more pointed compared to the snout of *Rasbora* cf. *notura* in this study, which is shorter and blunt (*Figure 4*). Currently, we regarded this species as another form of *R. notura* species, and it may be a complex which needs further taxonomic study.

Note: SDB - subdorsal blotch.

Figure 4. (a) The holotype of Rasbora notura *from Kottelat (2005), and (b)* Rasbora *cf.* notura *from this study.*

The species accumulation curves and the estimation of Chao 1 demonstrated that there should be more species to be recorded with the additional sampling efforts. The sampling efforts in terms of the number of individuals were the most appropriate measure suggested because it helps to avoid bias (Moreno and Halffter, 2001; Willott, 2001). We employed the electrofishing techniques in this study to maximise the sampling efforts, as the use of the method was proven to be more effective than the single hand-seining methods, thus increasing the chances of getting higher abundance and a higher diversity of fishes in the tropical streams (Deacon *et al*., 2017). In another study, Almeida *et al*. (2017) suggested that the species richness can be reasonably estimated if the transect length was 10 times the stream width or less. Several studies also proposed a transect length of 150 m (Meador *et al*., 2003) or a minimum of 50 m length to collect 90% of the species in the streams (Dauwalter and Pert, 2003; Patton *et al*., 2000). The suggested transect length also was corresponding to our transect length which was 90 m (for 3 plots). Future works on the fish inventories should be focusing on repetitive sampling, rather than single inventories, for documenting fish species richness in the tropical streams in Malaysia.

The species richness in total is relatively higher for a single data collection, (at every 30 m intervals along a 90 m reach), hence causing a relatively lower average species richness per stream (less than 15 species), compared to the earlier studies in the plantation areas (Ahmad *et al*., 2018; Aqmal-Naser and Ahmad, 2021). In terms of conservation, the fragmented habitat (monotonous habitat) within the streams in the oil palm plantations can affect the fish composition and beta diversity, especially the habitat-specialised fish. The rheophilic species depend on the gradient and high-water velocity for reproduction and development (Birnie-Gauvin *et al*., 2017). The rheophilic species in this area live in the fast-flowing and rapid water current and might need to migrate to the upper stream or another pristine habitat as the increase in sediment loading may cause habitat deterioration, which is not suitable for the fish. The heavy sediment loading in the streams associated with logging had shown a smaller number of fish species, and the absence of many rheophilic fish species compared to the moderately disturbed streams (Aqmal-Naser *et al*., 2020b).

The riparian reserves for the oil palm plantations are required by the law of the Malaysian Government in 1965 and mandatory for the participants of the Roundtable on Sustainable Palm Oil (RSPO) certification program (Giam *et al*., 2015). In addition, Malaysia also has the Malaysian Sustainable Palm Oil (MSPO) certification scheme which aims to establish a sustainable palm oil operation. It is also parallel to the fifth principle of RSPO, which is to ensure the conservation of biodiversity, natural resources, and the ecosystem by reducing pollution. It is crucial to have a riparian buffer to decrease the impact of disturbance on the aquatic ecosystems. The riparian buffer had successfully maintained fish species richness, functional diversity and biomass in the streams (Giam *et al*., 2015) and fish abundance (Deere *et al*., 2021) compared to the no riparian buffer zone in the oil palm monoculture of

Southeast Asia. Most of the streams sampled in this study did not have riparian reserves, which might explain the lower species richness recorded. Both RSPO and MSPO programs are known to guide the farmers with sustainability standards but whether they can maintain the aquatic biodiversity, remains a challenge with regard to law enforcement of the riparian reserves. Even though the species richness was considered lower, the estimated species richness still showed increasing trends and could indicate an altered habitat but with natural cycles which would possibly enable the fish diversity to be sustained. However, this requires continuous monitoring to validate the hypothesis**.**

CONCLUSION

Our study had shown that fish species richness in the oil palm plantations has two major importance; as ornamental and as food. Continuous inventories and monitoring are the keys to recording all known fish species inhabiting the oil palm agroecosystem. However, most of the species recorded at present are not very essential for fish species conservation. They bring some value to the local people and should be a priority in future planning regarding the expansion of oil palm plantations. The non-compliance of farmers on the riparian reserves will become the major factor that contributes to the reduction of fish diversity in this agroecosystem. It is necessary to continue protecting the primary forest reserve, and creating a riparian forest in the already established oil palm plantations, while at the same time, steering the possible win-win situations for both ecosystem function and human livelihood.

ACKNOWLEDGEMENT

We thank the Faculty of Science and Marine Environment, Universiti Malaysia Terengganu for the facilities and equipment provided for the sampling. Mohammad Zul Iqmal and Muhammad Fatihah Syafiq are gratefully acknowledged for their assistance during the sampling.

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