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A Preliminary Checklist of Fish Species in the Peat Swamp Forest of Ayer Hitam Utara State Park Forest, Johor, Malaysia

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ABSTRACT

Ayer Hitam Utara State Park Forest (AHUSPF) is an invaluable sanctuary in Johor, the last remaining intact peat swamp forest reserve that hosts many species unique to this distinctive habitat. Some rapid surveys conducted from 2019 to 2022 recorded 40 species of freshwater fish within AHUSPF. Notably, 11 are stenotopic to acid blackwater, and 12 are stenotopic to acid water, most belonging to the family Osphronemidae and Danionidae. The International Union for Conservation of Nature Red List has designated two species, *Encheloclarias curtisoma* and

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Betta persephone, as Endangered, while *Betta omega* is classified as Critically Endangered. The checklist presented herein was first produced from an inventory study in AHUSPF. The preservation of peat swamp forests in the area is under imminent threat due to the alarming rate of land conversion, forest fires, and the recent potential threat from the red-claw crayfish invasion in the aquatic environment. Hence, continuous monitoring is vital for documenting and updating the conservation status of the fish species. These endeavours will facilitate the development of practical conservation approaches to ensure the long-term sustainability of AHUSPF and its associated species.

Keywords: Acid blackwater, alien species, biodiversity inventory, conservation, endemic species, sustainable practices, threatened fish species

INTRODUCTION

Ayer Hitam Utara State Park Forest (AHUSPF) stands as the largest and the last remaining peat swamp forest reserve in Johor, Peninsular Malaysia, making it a crucial ecological stronghold (Ahmat & Norazlimi, 2022). Other forests in Johor have suffered significant fragmentation, leaving behind mere patches of the once-expansive peat swamp landscape (P. K. L. Ng et al., 1994; Wetlands International, 2010). Due to its gloomy appearance, characterised by a soft, spongy bottom, an abundance of decaying woods, and a dense understory of spiny vegetation, the biodiversity of the peat swamp forest has received limited attention (Posa et al., 2011). The unfavourable water conditions, including dark colouration, high acidity, and low dissolved oxygen levels, have perpetuated the fallacy of low aquatic biodiversity in peat swamps (P. K. L. Ng et al., 1994).

However, a paradigm shift occurred with a comprehensive study conducted by P. K. L. Ng et al. (1992) in the North Selangor Peat Swamp Forest, which recorded 47 species of freshwater fishes from the blackwater habitat, with 14 species regarded as stenotopic taxa (P. K. L. Ng et al., 1994). Subsequent studies conducted post-1992 revelation, such as in Ulu Sedili, Johor (Zakaria et al., 1999), Pondok Tanjung, Perak (Mansor et al., 1999), Sungai Bebar, Southeast Pahang (Amirrudin et al., 2005), Jambu Bongkok, Terengganu (Amirrudin et al., 2011), Kuala Langat, Selangor (Fahmi-Ahmad & Samat, 2015), Tasek Bera, Pahang (Fahmi-Ahmad et al., 2015), and North Selangor Peat Swamp Forest (Azmai et al., 2020), have further contributed to the understanding of aquatic biodiversity, specifically freshwater fishes, within peat swamp ecosystems.

Given the constant threats of climate change and urbanisation, which have led to substantial degradation and conversion of peatlands for industry, human settlements, and agriculture (Giam et al., 2012; Girkin et al., 2022; Roucoux et al., 2017), the fate of freshwater fish species dependent on peatland habitats has become a growing concern. The conversion of peatlands, particularly for oil palm plantations, has contributed to Malaysia's demise of peat swamp ecosystems (Manzo et al., 2020).

In Peninsular Malaysia, approximately 281,652 ha of peatland is dedicated to agriculture, with 72% utilised for oil palm plantations. Among the states, Johor holds the highest area of converted peatland into oil palm plantations, with 68,468 ha (Wetlands International, 2010). The once-extended peat swamp forests in southwest Johor have now been fragmented due to the increasing global demand for palm oil (Shevade & Loboda, 2019; Wetlands International, 2010).

AHUSPF, situated in North-West Johor, remains an intact and protected forest amidst the encroachment of small oil palm plantations, agriculture, and residential areas. The surrounding land-use changes could significantly impact the main forest and its unique freshwater fish biodiversity if not closely monitored. Despite its ecological importance, the diversity of fishes within AHUSPF has not been adequately documented. Thus, this study aims to present the first checklist of freshwater fish thriving in AHUSPF and illuminate the potential threats the fish and its habitat might encounter. By providing essential baseline data, this study could contribute to future conservation efforts to preserve the ecological integrity of AHUSPF and its valuable diversity of freshwater fishes.

MATERIALS AND METHODS

The AHUSPF is in the northwestern part of Johor, specifically in the Muar district, within the designated Ayer Hitam Utara Forest Reserve area (Figure 1). Encompassing 3,797 ha with a terrain elevation of approximately 31 m a.s.l., this area receives an average annual rainfall of 2,060 mm (Shamsuddin et al., 2021). The local economy in the area is predominantly reliant on agricultural activities. The land surrounding AHUSPF is mainly utilised for small-scale oil palm estates, alongside cultivating vegetables and fruit orchards. Fish collections were conducted during the Scientific Expedition on Biological Diversity in AHUSPF from April 15th to April 16th, 2019, followed by biannual visits in 2021 and 2022. During each biannual visit, fish collection activities spanned three days. The first visit for each year occurred in April, the dry period, while the second visit took place in November, during the wet period.

This study utilised the purposive sampling method, wherein the sampling sites were chosen based on expert judgment, particularly when targeting specific habitats for certain species. This approach is suitable for preliminary studies to gain a broader understanding of the fish community in the area. The study site represents a typical peat swamp forest environment with loose soil and substrate consisting of wood branches, submerged vegetation, and dead leaves from surrounding trees (Ahmad & Samat, 2015).

The pH for the blackwater area ranged from 3.6 to 3.8, while for the freshwater swamp, it ranged from 4.8 to 5.4. The blackwater area is in the main forest area, characterised by isolated pools of water among forested hummocks during the dry period. These pools become interconnected during the rainy season when the forest

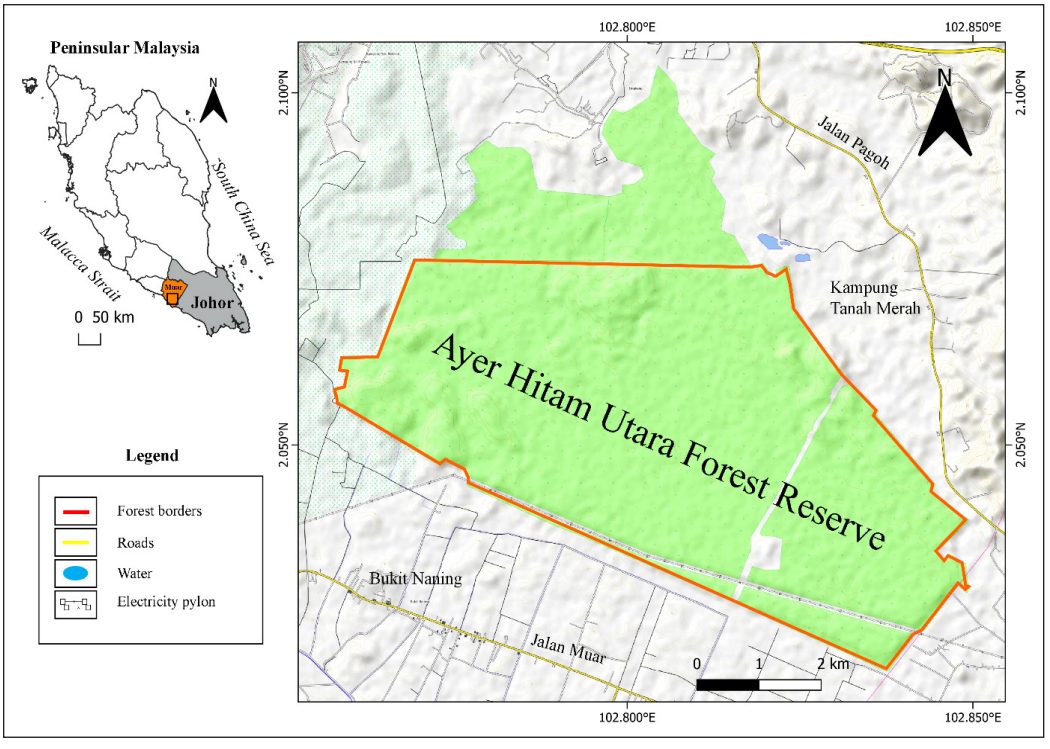

Figure 1. Map of the study area in Ayer Hitam Utara State Park Forest, Johor, Peninsular Malaysia

floor becomes flooded. Adjacent to the main peat swamp forest, in the peripheral area of AHUSPF is a flooded forest housing a freshwater swamp stream. The water in this stream is slow-moving and appears murky, resembling the colour of milk tea. Despite originating from the nearby peat swamp forest, the water in the stream is less acidic compared to the main forest (Figure 2).

Scoop net (1 mm mesh size) was the primary method gear throughout this study. The lightweight and easy-to-handle features in tight space made the scoop net the most effective gear. Cast nets (19.05 mm mesh size) and fish traps (25.4 mm mesh size) were alternative gears used in the spacious canals or streams. Fish were identified in the field and released back to the swamp whenever possible. A small representative sample was fixed in 10% formalin solution (diluted from formaldehyde solution 37%, Systerm Chemicals, Malaysia) and later preserved in 70% alcohol (diluted from ethyl alcohol 95% denatured, Systerm Chemicals, Malaysia) for long-term preservation. Voucher specimens were deposited in the Makmal Rujukan Zoologi at Universiti Sains Malaysia (USMFC) and Muzium Zoologi Universiti Malaya (UMKL).

The historical records of fishes from Ayer Hitam Forest Reserve, which are in the collection of local institutions, were also included. All caught fish were identified based on the general diagnostic characteristics following Zakaria-Ismail et al. (2019) and the taxonomic key of

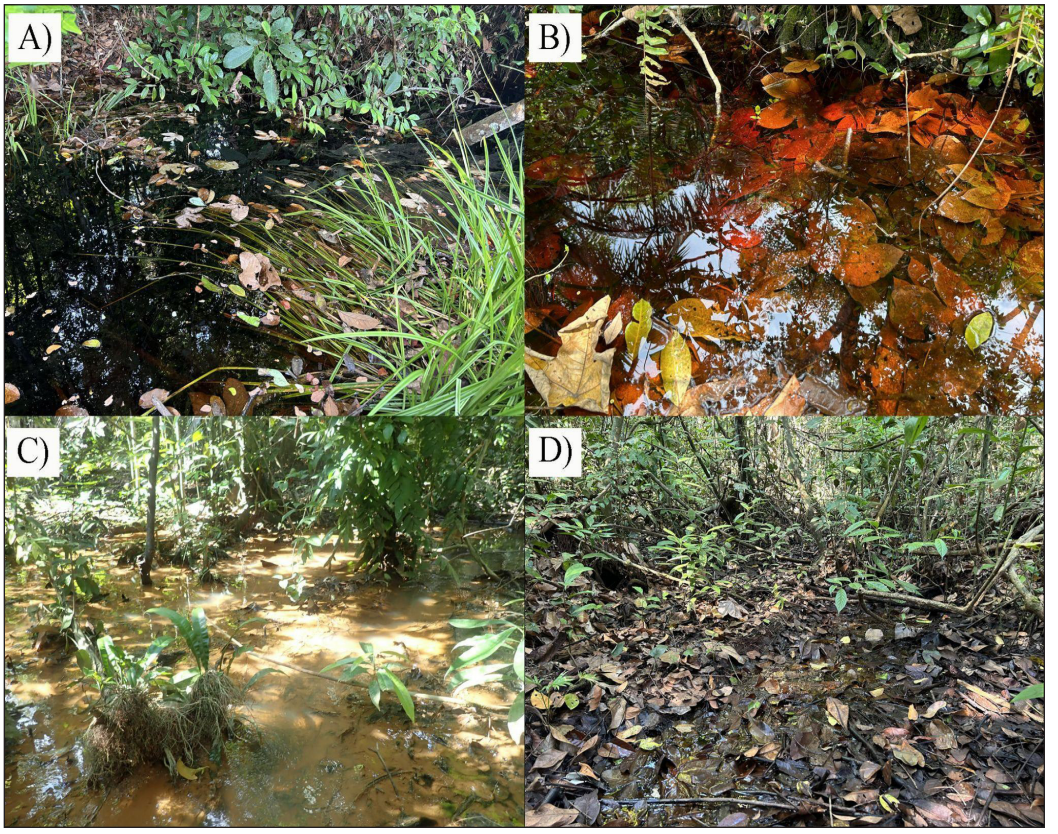

Figure 2. Overview of the habitats in the Ayer Hitam Utara State Park Forest: A) Blackwater habitat; B) Water in the forest darkened by tannins leached from fallen leaves; C) Freshwater swamp in the flooded forest; D) Puddles on the forest floor serving as fish refuges during the dry period

Kottelat et al. (1993) and Rainboth (1996). The fish systematic arrangement follows California Academy of Sciences (CAS) (n.d.) and Kottelat (2013). The abbreviation 'ex.' next to the number of materials examined means the exemplar or specimen. Habitat preferences were determined using recommendations by P. K. L. Ng et al. (1994). Stenotopic acid blackwater species are specifically adapted to highly acidic (pH 3 to 4) and dark-coloured blackwaters. Stenotopic acid water species thrive in acidic waters with a pH below 6; some may tolerate blackwaters. Eurytopic species are highly adaptable, commonly found, and thrive across a wide range of habitats, from slightly acidic to alkaline conditions. It is important to note that these habitat preferences are not solely based on water pH but on observations and expert verdicts. Species not classified by P. K. L. Ng et al. (1994) were assigned categories based on our experience and current knowledge about the fish. The International Union for Conservation of Nature (IUCN) status for all fish species recorded was based on The IUCN Red List of Threatened Species version 2022-2 (IUCN, 2022).

RESULTS

A total of 40 species representing 15 families of freshwater fishes were recorded in AHUSPF (Table 1 and Figure 3). The list of fish species in AHUSPF was dominated by the family Osphronemidae (10 species), followed by Danionidae (six species) and Channidae (five species). Only one species was encountered in each of the following families: Bagridae, Akysidae, Mastacembelidae, Chaudhuriidae, Synbranchidae, Anabantidae, Helostomatidae, and Zenarchopteridae. One species, *Betta persephone* from the family Osphronemidae, was reported as endemic to AHUSPF. Most of the fishes were caught in the blackwater habitats. In the freshwater swamp stream adjacent to the peat swamp forest within AHUSPF, the cyprinids (e.g., *Barbodes sellifer* and *Osteochilus vittatus*) and the rasborines (e.g., *Rasbora elegans* and *Rasbora myersi*) were commonly found thriving in the less acidic conditions of this habitat.

Table 1 shows 11 species of fish that are stenotopic to acid blackwater, 12 that are stenotopic to acid water, and 17 that are eurytopic. The high number of stenotopic

Table 1
Checklist of fishes from Ayer Hitam Utara State Park Forest with habitat preference and International Union for Conservation of Nature (IUCN) Red List status (2022) for each species

No.	Family	Species	Habitat preference	IUCN Red List status
1	Cobitidae	*Lepidocephalichthys tomaculum*	A	LC
2		*Kottelatlimia katik*	S	LC
3	Cyprinidae	*Barbodes sellifer*	E	NE
4		*Desmopuntius hexazona*	A	LC
5		*Osteochilus vittatus*	E	LC
6	Danionidae	*Boraras maculatus*	A	LC
7		*Esomus metallicus*	E	LC
8		*Rasbora einthovenii*	A	LC
9		*Rasbora elegans*	E	LC
10		*Rasbora kalochroma*	S	LC
11		*Rasbora myersi*	E	LC
12	Bagridae	*Mystus bimaculatus*	S	NT
13	Akysidae	*Parakysis verrucosus*	A	VU
14	Siluridae	*Ompok fumidus*	S	NT
15		*Silurichthys indragiriensis*	A	NT
16	Clariidae	*Clarias leiacanthus*	E	LC
17		*Clarias macrocephalus*	E	DD
18		*Clarias nieuhofii*	A	LC
19		*Encheloclarias curtisoma*	S	EN
20	Mastacembelidae	*Macrognathus circumcinctus*	A	LC
21	Chaudhuriidae	*Bihunichthys monopteroides*	A	VU
22	Synbranchidae	*Monopterus javanensis*	E	LC
23	Anabantidae	*Anabas testudineus*	E	LC

Table 1 *(continue)*

No.	Family	Species	Habitat preference	IUCN Red List status
24	Helostomatidae	*Helostoma temminckii*	A	LC
25	Osphronemidae	*Belontia hasselti*	S	LC
26		*Betta bellica*	A	LC
27		*Betta coccina*	S	VU
28		*Betta omega*	S	CR
29		*Betta persephone*	S	EN
30		*Betta pugnax*	E	LC
31		*Luciocephalus pulcher*	A	LC
32		*Sphaerichthys osphromenoides*	S	DD
33		*Trichopodus trichopterus*	E	LC
34		*Trichopsis vittata*	E	LC
35	Channidae	*Channa bankanensis*	S	NT
36		*Channa limbata*	E	NE
37		*Channa lucius*	E	LC
38		*Channa melasoma*	E	LC
39		*Channa striata*	E	LC
40	Zenarchopteridae	*Hemirhamphodon pogonognathus*	E	LC

Note. S = Stenotopic to acid blackwaters; A = Stenotopic to acid waters; E = Eurytopic (acidic to neutral or slightly alkaline); NE = Not Evaluated; DD = Data Deficient; LC = Least Concern; NT = Near Threatened; VU = Vulnerable; EN = Endangered

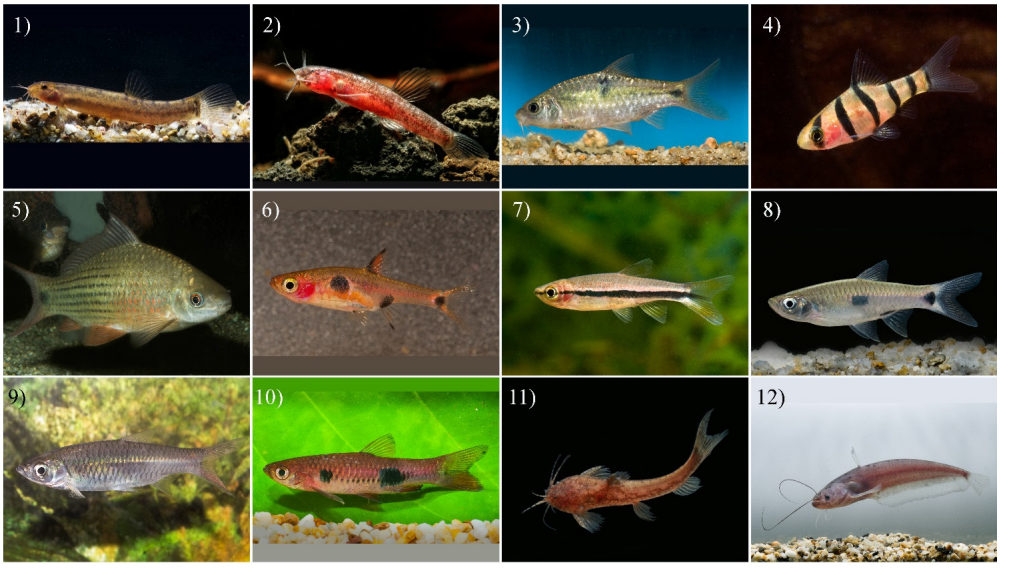

Figure 3. Freshwater fishes recorded in Ayer Hitam Utara State Park Forest: 1) *Lepidocephalichthys tomaculum*; 2) *Kottelatlimia katik*; 3) *Barbodes sellifer*; 4) *Desmopuntius hexazona*; 5) *Osteochilus vittatus*; 6) *Boraras maculatus*; 7) *Rasbora einthovenii*; 8) *Rasbora elegans*; 9) *Rasbora myersi*; 10) *Rasbora kalochroma*; 11) *Parakysis verrucosus*; and 12) *Ompok fumidus*

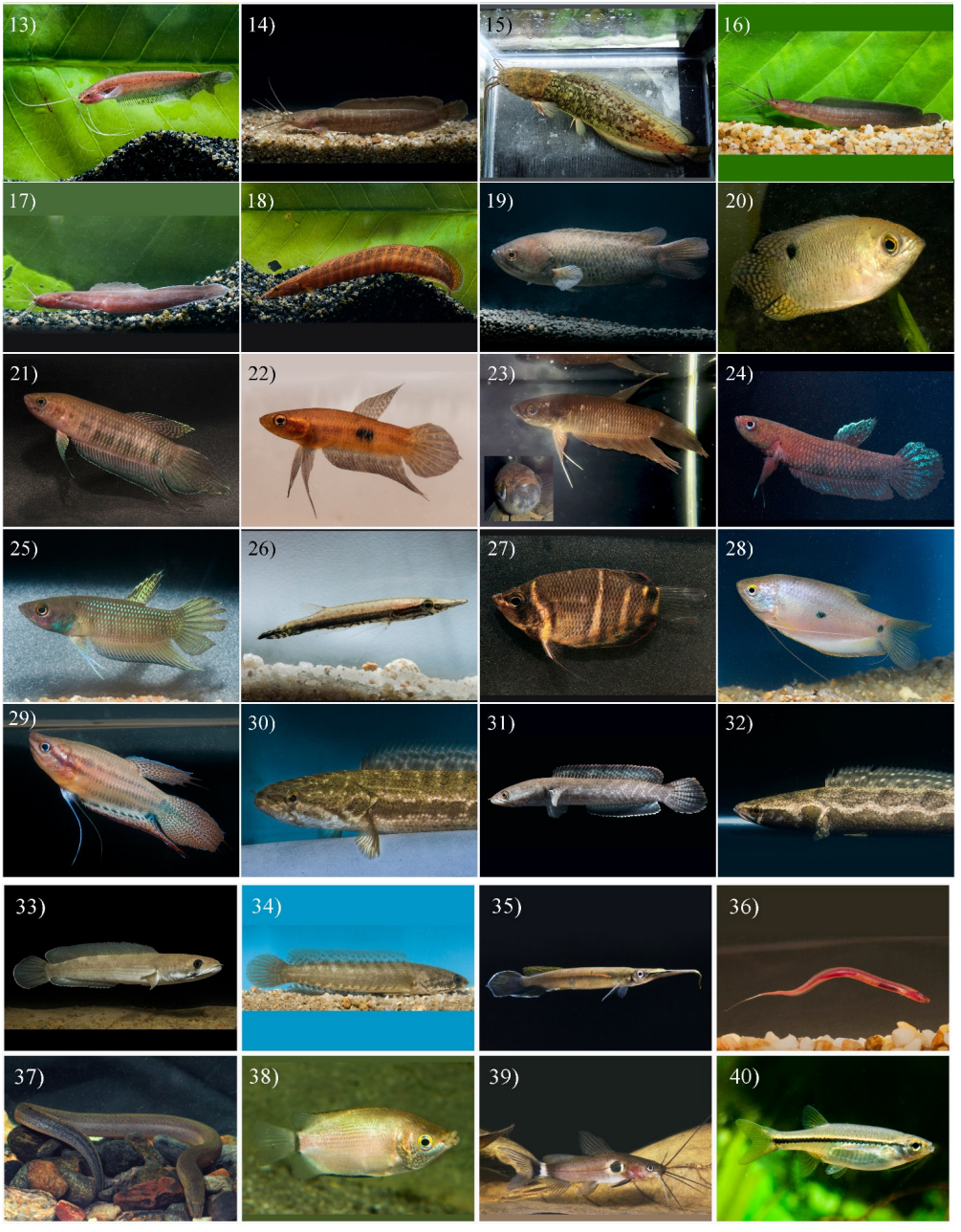

Figure 3 (continue). 13) *Silurichthys indragiriensis*; 14) *Clarias leiacanthus*; 15) *Clarias macrocephalus*; 16) *Clarias nieuhofii*; 17) *Encheloclarias curtisoma*; 18) *Macrognathus circumcinctus*; 19) *Anabas testudineus*; 20) *Belontia hasselti*; 21) *Betta bellica*; 22) *Betta coccina*; 23) *Betta omega*; 24) *Betta persephone*; 25) *Betta pugnax*; 26) *Luciocephalus pulcher*; 27) *Sphaerichthys osphromenoides*; 28) *Trichopodus trichopterus*; 29) *Trichopsis vittata*; 30) *Channa bankanensis*; 31) *Channa limbata*; 32) *Channa lucius*; 33) *Channa melasoma*; 34) *Channa striata*; 35) *Hemirhamphodon pogonognathus*; 36) *Bihunichthys monopteroides*; 37) *Monopterus javanensis*; 38) *Helostoma temminckii*; 39) *Mystus bimaculatus*; and 40) *Esomus metallicus*

to blackwater (five species) came from the family Osphronemidae. A total of six species belong to the threatened categories: Critically Endangered (CR), Endangered (EN), and Vulnerable (VU). *Betta omega* has been listed as CR, meanwhile *Betta persephone* and *Encheloclarias curtisoma* have been included as EN, and *Parakysis verrucosus*, *Bihunichthys monopteroides*, and *Betta coccina* have been listed as VU. Most of the fish species that occurred in AHUSPF are listed as Least Concern (LC), comprising 26 species. Additionally, four species are listed as Near Threatened (NT), two species as Not Evaluated (NE), and two species fall within the Data Deficient (DD) category, lacking information for further IUCN assessments (Table 1).

Annotated Checklist of Freshwater Fishes of Ayer Hitam Utara State Park Forest

Order Cypriniformes

Family Cobitidae

Lepidocephalichthys tomaculum Kottelat & Lim

Material Examined. 1 ex., UMKL 12739; 8 ex., UMKL 12782.

Kottelatlimia katik (Kottelat & Lim)

Material Examined. 1 ex., UMKL 12760; 1 ex., USMFC (10) 00019.

Remarks. This species is small in size. The size of an adult is about 13.5 mm in standard length (Kottelat & Lim, 1992). AHUSPF is the second locality in Peninsular Malaysia to record the occurrence of this species after Mawai, Kota Tinggi, Johor.

Family Cyprinidae

Barbodes sellifer Kottelat & Lim

Material Examined. 11 ex., UMKL 12778.

Remarks. Previously known as *Barbodes banksi*. However, morphological and molecular studies indicate that the populations in Peninsular Malaysia and Singapore are distinct from Borneo *B. banksi*, and this population has not yet been described (C. K.-C. Ng & Tan, 2021; Fahmi-Ahmad et al., 2020; Sobri et al., 2021). Recently, Kottelat and Lim (2021) described a new species, namely *Barbodes sellifer,* for the Peninsular Malaysia and Singapore population, while *B. banksi* is restricted to western Borneo.

Desmopustius hexazona (Weber & de Beaufort)

Material Examined. 8 ex., UMKL 12413; 4 ex., UMKL 12738; 2 ex., UMKL 12750; 2 ex., UMKL 12787; 3 ex., USMFC (7) 00195.

Osteochilus vittatus (Valenciennes, in Cuvier & Valenciennes)

Material Examined. 1 ex., UMKL 12864

Remarks. This species was observed in the streams in the AHUSPF.

Family Danionidae

Boraras maculatus (Duncker)

Material Examined. 16 ex., UMKL 12414; 7 ex., UMKL 12736; 12 ex., UMKL 12752.

Remarks. This species has been described from Bukit Treh, Muar. However, the population from the type locality no longer exist, and the population in AHUSPF is the closest to the type locality. The body colour

is bright red; this species is famous as an ornamental fish.

Esomus metallicus Ahl

Material Examined. 2 ex., UMKL 12865.

Remarks. Found abundantly in the drainage system adjacent to AHUSPF.

Rasbora einthovenii (Bleeker)

Material Examined. 3 ex., UMKL 12866.

Remarks. This species is commonly found in the flowing blackwater in the AHUSPF.

Rasbora elegans Volz

Material Examined. 11 ex., UMKL 12779.

Rasbora kalochroma (Bleeker)

Material Examined. 1 ex., UMKL 12415; 5 ex., UMKL 12742; 1 ex., UMKL 12759; 1 ex., UMKL 12777.

Remarks. This rasborine species is only found in the acid blackwater habitat. Has a reddish body colour. This species is popular as an ornamental fish.

Rasbora myersi Brittan

Material Examined. 3 ex., UMKL 12867.

Remarks. This species was observed in the slow-moving, murky water streams in the AHUSPF.

Order Siluriformes

Family Bagridae

Mystus bimaculatus (Volz)

Material Examined. 1 ex., UMKL 12863.

Remarks. The occurrence of this species in this area recorded the southernmost distribution of this species in Peninsular Malaysia.

Family Akysidae

Parakysis verrucosus Herre

Material Examined. 2 ex., UMKL 12776.

Family Siluridae

Ompok fumidus Tan & Ng

Material Examined. 1 ex., UMKL 12743.

Silurichthys indragiriensis Volz

Material Examined. 7 ex., UMKL 12746.

Family Clariidae

Clarias leiacanthus Bleeker

Material Examined. 1 ex., UMKL 12788.

Clarias macrocephalus Günther

Material Examined. 1 ex., UMKL 12868.

Clarias nieuhofii Valenciennes, in Cuvier & Valenciennes

Material Examined. 3 ex., UMKL 12745.

Encheloclarias curtisoma Ng & Lim

Material Examined. 2 ex., UMKL 12753; 3 ex., USMFC (19) 00012.

Remarks. Specimens examined have a total number of dorsal fins 24–26; the total number of anal fins 47–48; pectoral spine serrae 6–7; and a total number of gills rakers 9. Tentatively, it is identified as *Encheloclarias curtisoma*, a species previously recorded only in North Selangor Peat Swamp Forest, Selangor (Azmai et al., 2020; P. K. L. Ng & Lim, 1993).

Order Synbranchiformes

Family Mastacembelidae

Macrognathus circumcinctus (Hora)

Material Examined. 2 ex., UMKL 12747.

Family Chaudhuriidae

Bihunichthys monopteroides Kottelat & Lim

Material Examined. Uncatalogued USMFC

Remarks. This species has a small adult size (40 mm) and may be considered

miniaturised (Britz & Kottelat, 2003). Typically found in the bottom substrate with the leaf litter. This species seems restricted to the highly acidic black waters in peat swamp forests. Interestingly, it is named for its resemblance to rice vermicelli, a variety of very slender noodles served in many Asian countries, known as 'bihun' in Malay or 'bee hoon' in Hokkien Chinese (Kottelat & Lim, 1994).

Family Synbranchidae

Monopterus javanensis La Cepède

Material Examined. 2 ex., UMKL 12869.

Remarks. This species is commonly found in ditches near the AHUSPF. Locals usually catch this fish using a hook and line baited with an earthworm.

Order Anabantiformes

Family Anabantidae

Anabas testudineus (Bloch)

Material Examined. 1 ex., UMKL 12870.

Family Helostomatidae

Helostoma temminckii (Cuvier)

Material Examined. 2 ex., UMKL 12871.

Remarks. The only species from the family Helostomatidae.

Family Osphronemidae

Belontia hasselti (Cuvier, in Cuvier & Valenciennes)

Material Examined. 3 ex., UMKL 12872.

Betta bellica Sauvage

Material Examined. 9 ex., UMKL 12412; 7 ex., UMKL 12748; 4 ex., UMKL 12785; 2 ex., USMFC (37) 00009.

Remarks. It is the largest bubble-nesting *Betta* and is only found in the blackwater stream.

Betta coccina Vierke

Material Examined. 3 ex., UMKL 12751; 1 ex., UMKL 12775; 7 ex., UMKL 12737.

Remarks. In Malaysia, this species can only be found in AHUSPF.

Betta omega Tan & Ahmad

Material Examined. 2 ex., UMKL 12862.

Remarks. The fish has been described from a small area in the southern part of Johor. The occurrence of this species in AHUSPF has expanded its distribution.

Betta persephone Schaller

Material Examined. 4 ex., UMKL 12741; 10 ex., UMKL 12749; 28 ex., UMKL 12783; 3 ex., USMFC (37) 00020; 2 ex., USMFC (37) 00051.

Remarks. This species is endemic to AHUSPF.

Betta pugnax (Cantor)

Material Examined. 6 ex., UMKL 12786.

Luciocephalus pulcher (Gray)

Material Examined. 1 ex., UMKL 12740; 1 ex., UMKL 12758.

Sphaerichthys osphromenoides Canestrini

Material Examined. 7 ex., UMKL 12755; 1 ex., UMKL 12784; 2 ex., USMFC (37) 00008.

Remarks. Commonly known as Chocolate Gourami, this fish has a chocolate colour with golden bands running down their bodies. It is one of the two maternal mouthbrooders in the genus, including *Sphaerichthys selatanensis*. The female carefully tends to the eggs in her mouth until they hatch.

Trichopodus trichopterus (Pallas)

Material Examined. 1 ex., UMKL 12781; 2 ex., UMKL 12744.

Trichopsis vittata (Cuvier, in Cuvier & Valenciennes)

Material Examined. 7 ex., UMKL 12754.

Family Channidae

Channa bankanensis (Bleeker)

Material Examined. 4 ex., UMKL 12756.

Remarks. Stenotopic to the acid blackwater habitat.

Channa limbata (Cuvier)

Material Examined. 1 ex., UMKL 12757.

Channa lucius (Cuvier)

Material Examined. 1 ex., USMFC (38) 00045.

Channa melasoma (Bleeker)

Material Examined. 1 ex., USMFC (38) 00025; 1 ex., USMFC (38) 00026.

Channa striata (Bloch)

Material Examined. 2 ex., UMKL 12873.

Order Beloniformes

Family Zenarchopteridae

Hemirhamphodon pogonognathus (Bleeker)

Material Examined. 3 ex., UMKL 12874.

DISCUSSION

The declining peat swamp forest area in Peninsular Malaysia is a pressing concern despite some areas being protected. However, the knowledge of fish inhabiting these forests, especially AHUSPF, remains limited. This study recorded 40 species of freshwater fishes in AHUSPF, with over half being stenotopic to acid blackwater and acid water categories. These findings underscore the rich diversity and ecological significance of AHUSPF's freshwater fish community, laying the foundation for conservation and ecological arguments.

Johor and Selangor are among the states with the largest peatland areas in Peninsular Malaysia (Wetlands International, 2010). Comparing AHUSPF to the extensively studied North Selangor Peat Swamp Forest (NSPSF) reveals several intriguing insights. While AHUSPF recorded a lower number of freshwater fish species (40) compared to NSPSF (124) (Azmai et al., 2020), it is notable that the number of stenotopic acid blackwater and acid water species (23) remains relatively high, as observed in NSPSF (65)—accounting for over half of the total number of species in each respective site. It features the importance of peat swamp forests in upholding fish specialists and endemic species (Posa et al., 2011). Additionally, AHUSPF has documented range extensions for certain species in Peninsular Malaysia, such as *Mystus bimaculatus* and *Encheloclarias curtisoma*, which were previously reported only in NSPSF (P. K. L. Ng et al., 1992; P. K. L. Ng & Lim, 1993). Despite being protected forests, AHUSPF and NSPSF face ongoing pressure from surrounding agricultural activities. In NSPSF, evidence of illegal encroachment involving oil palm plantations has been observed, leading to an expansion of oil palm areas along the forest fringes (Charters et al., 2019). Without sustainable management, the protected areas will end up becoming isolated and consequently affected by changes in their properties and function (Anamulai et al.,

2019; Word et al., 2022). Emphasising good practices in oil palm monoculture, such as protecting riparian buffer zones, can contribute to sustaining freshwater fish biodiversity (Aqmal-Naser et al., 2022) and preserving the peat swamp forest as a vital habitat for fish species. Acknowledging the potential impact of similar agricultural developments on AHUSPF in the future, given the current trends observed in NSPSF and the country's economic growth, is crucial.

Freshwater fish assemblage within the blackwater of AHUSPF remains highly vulnerable to various threats despite their unique adaptation to this specific habitat. Studies have shown a consensus that anthropogenic factors, including overexploitation, habitat change, fragmentation, biological invasions, and climate change, are key factors contributing to species vulnerability (Albert et al., 2021; Pouteau et al., 2022). Deforestation and drainage for agricultural purposes are prominent threats to the peat swamp forest ecosystem (Austin et al., 2019; Miettinen et al., 2016). Local communities resorting to quick land-clearing methods involving fire could hoist peatland degradation (Cole et al., 2019). Uncontrolled fires can rapidly spread, encroaching into adjacent areas and posing a significant risk to the freshwater fish assemblage and overall ecosystem. Figure 4A depicts the forest fire that occurred in 2020 within AHUSPF. The phenomenon is believed to be associated with land exploitation activity in the forest reserve's peripheral area. The fire, initially lit for land clearing purposes, promptly spread to the nearby forest during drought, causing devastating effects on the ecosystem. The peatland fires affect not only the adjacent forest reserve's well-being but also the health of local people, as they can cause air pollution and, in turn, respiratory disease (Hein et al., 2022). Despite these threats, effective conservation planning and efforts can help combat the adverse impact of land conversion and forest fire on peat swamp forests (Charters et al., 2019).

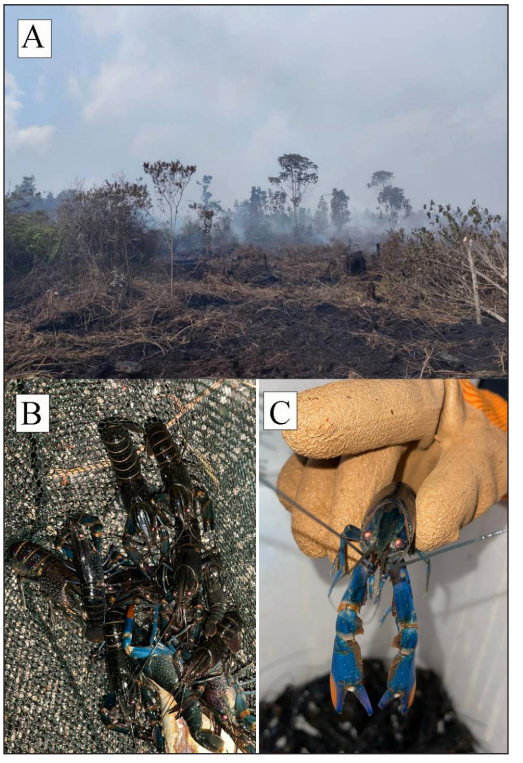

Figure 4. A) The 2020 forest fire in Ayer Hitam Utara State Park Forest resulted in the catastrophic destruction of vegetation and peat soil. This devastation is linked to agricultural activities, including land clearing and the drainage of peatlands; B) and C) The red-claw crayfish, *Cherax quadricarinatus,* from the adjacent area of AHUSPF (Photo by Norhidayah Haris)

Apart from land opening for plantation purposes, the potential threat of alien species also warrants consideration. While this study did not record the presence of alien species within the AHUSPF area, there have been reports of the red-claw crayfish, *Cherax quadricarinatus* von Martens, in AHUSPF peripheral areas, likely resulting from accidental or deliberate release from aquaculture facilities (Figures 4B and 4C). Originally native to freshwater habitats of Australia and Papua New Guinea, *C. quadricarinatus* has already established feral populations in many parts of the world, including Malaysia and Singapore (Ahyong & Yeo, 2007; Naqiuddin et al., 2016). This species was first introduced in Malaysia, specifically in Johor states, for the aquarium and aquaculture industry in the 1980s (Naqiuddin et al., 2016).

Cherax quadricarinatus is recognised as an invasive species due to its burrowing behaviour, which causes damage to riverbanks and generates public concern (Jabatan Pertanian Malaysia, 2021). Its high tolerance to low dissolved oxygen and pH environments (Haubrock et al., 2021; Reynolds et al., 2013) has enabled its appearance in the blackwater canal at the AHUSPF border. Although not currently found within AHUSPF, the connected drainages between the reservoir and the forest streams and swamps could serve as potential dispersal corridors, posing a threat to the native species of AHUSPF. Its adults' ecological roles are similar to benthic fishes, potentially leading to competition and disadvantages for the native fishes (Reynolds et al., 2013). Raising awareness of the possible impact of this alien species on native fishes and fostering collaboration between the local community and the Fishery Department is essential to combat the expansion of the red-claw crayfish population.

Six species from AHUSPF require significant attention from all stakeholders based on their IUCN Red List status. *Parakysis verrucosus*, *Bihunichthys monopteroides*, and *Betta coccina* have a VU status. *Encheloclarias curtisoma* and *Betta persephone* are classified as EN. The only species in CR status is *Betta omega*. These six species are all classified as stenotopic to acid blackwater and acid water, which rely heavily on peat swamp forests for their survival to maintain their already distressed population. The findings of *Encheloclarias curtisoma* in this study have increased its distribution range to the southwest of Peninsular Malaysia and lessened the pressure of this species to become extinct regionally. Its congener *Encheloclarias kelioides*, reported from Pahang and the east of Johor, has been assessed as CR and ostensibly extinct (Ahmad, 2019). *Betta persephone* is another species with a narrow distribution, i.e., endemic to the western part of Johor (Tan & Ng, 2005).

Given the recent rapid land utilisation for development, AHUSPF has become the last extensive haven for this species. The risk of endemic species extinction due to human socio-economic disturbances is a pressing concern in conservation biology. The increase in human population and socio-economic hardships have contributed to the erosion of biological diversity much

faster than historical extinction rates (Fonzo et al., 2013; Semmelmayer & Hackländer, 2020). The high rate of discovering fish species that are new to science and high endemicity has highlighted the importance of the peat swamp forest ecosystem (Azmai et al., 2020; Kottelat et al., 2006; Tan & Ng, 2005). For instance, *Betta omega*, a recently described species found in the remnants of the peat swamp (i.e., oil palm plantation ditches) in Johor's southwestern region, faces challenges due to the lack of connection to healthy forests, resulting in its CR status (Ahmad & Low, 2019; Tan & Ahmad, 2018). Endemic species face an even higher extinction risk due to expected habitat loss, particularly in regions where these remaining endemic species are largely unprotected (Gonçalves-Souza et al., 2020). Nonetheless, this study has provided some relief as the population of *Betta omega* in AHUSPF is extended and in better ecological condition compared to its type locality.

Protected areas like AHUSPF play a crucial role in conserving biodiversity; however, they may not be sufficient to negate the impact of anthropogenic species extinction (Ceballos et al., 2020). To effectively mitigate the risk of endemic species extinction in AHUSPF, conservation strategies should implement a comprehensive approach that considers the intricate interplay between human activities and societal response (Lee & Jetz, 2011). It calls for collaborative efforts involving various stakeholders at local and national levels. Integrating technological advancements alongside economic and regulatory stimuli could encourage local communities, farmers, consumers, and companies to adopt sustainable practices (Albert et al., 2021; Barbier, 2017).

Besides, documenting and assessing the local extinction threat faced by endemic species is of utmost importance. The state and national species red list needs to be meticulously developed and consistently updated to identify and address local threats effectively. The most essential and ongoing efforts are to strengthen public education and raise awareness about the conservation of AHUSPF and its endemic species through awareness campaigns, educational programs, and active community engagement. While in species-specific conservation priorities, it is crucial not to overlook miniature species, as the conventional approach tends to prioritise larger and charismatic species, inadvertently risking the extinction of small endemic fishes that inhabit the peat swamp forest (Collares-Pereira & Cowx, 2004). Here *Betta persephone* is proposed as the prime candidate and theme for targeted conservation efforts within AHUSPF.

Continuous and comprehensive monitoring of the fish assemblage in AHUSPF is vital to detect species and ecosystem health changes. Early detection enables prompt and appropriate action by stakeholders to prevent biodiversity decline. Future studies should investigate the link between fish species abundance and composition with AHUSPF's ecosystem to understand how the changes in fish diversity affect the ecosystem. More information is

needed on the past and current condition of AHUSPF and its freshwater fish diversity to predict their future response to changes. Additionally, evaluating AHUSPF efficacy as a secure haven for freshwater fish through comparisons with agriculture areas, monoculture sites, and other degraded ecosystems will yield valuable insights to bolster conservation efforts and promote sustainable practices. AHUSPF can strengthen its role in safeguarding endemic species and contribute significantly to global conservation efforts.

CONCLUSION

The preliminary checklist of fish species in this study underlines the significance of embracing sustainable practices to protect the rich fish diversity within AHUSPF. These measures and the proposed conservation initiatives serve as invaluable tools in advocating biodiversity preservation and sustainable management, especially in the face of mounting anthropogenic pressures. Despite being a protected area, the AHUSPF faces challenges from surrounding land use and invasive alien species, which should not be underestimated. Collaborative initiatives, public engagement, and continuous monitoring are imperative to realise the proposed conservation efforts and guarantee this vital ecosystem's long-term health and resilience. By aligning conservation efforts with sustainable practices, a harmonious coexistence between human activities and nature will be fostered, ensuring the lasting protection of AHUSPF's precious biodiversity for generations to come.

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