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Review Article

A Review of the Ichthyofauna of Malaysian Peat Swamp Forest

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ABSTRACT

A review of literature showed that numerous intensive surveys have been carried out on the ichthyofauna of the peat swamp forests (PSFs) of Malaysia. This review aims to provide a checklist of blackwater fish species in Malaysia from available published literature, and address their economical importance, conservation status and problems of PSFs. A total of 198 peat swamp fish species from 32 families have been recorded in Malaysia. From this number, a total of 114 species from 23 families, representing about 40% of the known fish fauna in Peninsular Malaysia, were recorded from north Selangor PSF. Meanwhile, a total of 49 species belonging to 18 families, 13 species from seven families, 58 species belonging to 19 families, and nine species from five families were recorded from the peat swamps of Perak, Johor, Pahang and East Peninsular Malaysia (parts of Pahang and Terengganu), respectively. Meanwhile, 31 species from 12 families and 40 species belonging to 13 families were recorded from Sabah and Sarawak, respectively. Family Cyprinidae has the highest recorded species, followed by Osphronemidae, Bagridae and Siluridae. The IUCN Red List revealed 12 threatened species facing risk of extinction. The importance of conserving PSFs was outlined and suggestions made in line with the objectives of conservation. Findings from literature revealed that Malaysia's PSFs are rich in fish diversity, contrary to previous belief, and should therefore be conserved and protected to ensure the richness of their fish diversity.

Keywords: Ichthyofauna, peat swamp forest, conservation, Malaysia

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INTRODUCTION

Peat swamp forests (PSFs) are one of the most unusual and harsh ecosystems in the tropical rainforest biome. The PSFs of Peninsular Malaysia are one of the most threatened (illegal logging, irrigation of oil palm and paddy fields), yet one of the most poorly understood biotopes (Ng et al*.,* 1994). These swamps derive their name from their substrate of peat consisting of plant detritus, which gradually release tannins and organic acids into poorly buffered water and contribute to its characteristically low pH (Ng et al*.,* 1994; Yule, 2010; Posa et al*.,* 2011; Wantzen et al*.,* 2011). Peat swamps are typically deficient in oxygen, which is one consequence of plant decay (Beamish et al*.,* 2003). Peat swamps are generally referred as 'black waters', while waters originating from PSFs are highly acidic with pH values ranging from 3.6 to 5.9, tea-coloured when seen against transmitted light, and black when seen en masse via reflected light (Johnson, 1967ab; 1968). Generally, the acidity of black waters is due to the high concentrations of humic acids and other phenolic acids (Goltenboth, 2006; Irvine et al., 2013).

Most of the black waters of Singapore and Peninsular Malaysia recorded by Wyatt-Smith (1959; 1964), Johnson (1967a; 1968), Anderson (1983) and Whitmore (1984; 1988) have been converted to agriculture, industrial states and residential areas (Ng et al*.,* 1994). The peat swamp forests of Johor, which were of staggering vastness in Peninsular Malaysia, are almost completely degraded. Peat swamp forests of considerable size in Peninsular Malaysia are now restricted to north Selangor, central Terengganu and Pahang (Ng et al*.,* 1994). In Peninsular Malaysia, the fish fauna of the PSF of north Selangor is comparably well studied and recorded.

The unique characteristics of black waters (dark colour, low dissolved oxygen and high acidity) led to an initial misinterpretation of 'habitat inhospitality', and the conclusion that such habitat will sustain very poor faunal diversity. One of the earliest surveys of the fish fauna of Malaysia peat swamps was by Johnson (1967ab; 1968) who recorded only 26 species in black waters, of which only one is stenotopic to black water. However, the first well-recognised documentation of blackwater fish species of the north Selangor peat swamp forest (NSPSF) was done by Davies and Abdullah (1989). Numerous other surveys have also been conducted on the ichthyofauna of Peninsular Malaysia (Shiraishi et al*.,* 1972; Lim et al*.,* 1982; Mizuno & Furtado, 1982; Zakaria-Ismail, 1990; Ng & Lim, 1991; Ng et al*.,* 1992, 1994; IPT-AWB, 1993; Lee & Ng, 1994; Zakaria et al*.,* 1999; Lee, 2001; Beamish et al*.,* 2003; Rezawaty, 2004; Shah et al*.,* 2006; Ahmad et al*.,* 2013; Ismail et al*.,* 2013; Siow et al*.,* 2013).

The objectives of this review are to provide a checklist of black water fish species in Malaysia, assess their economic importance, update the conservation status of the species and address the conservation problems of PSFs. An exhaustive search of published literature was conducted to

collate lists and determine the distribution of the peat swamp fishes from surveys in Malaysian PSF sites (Figure 1). Fish species provided in this review were recorded from the surveys between 1989 and 2015. Reference was made to Kottelat's catalogue of the fishes of southeast Asia (Kottelat, 2013) to verify and update taxonomic revisions of species.

FISH SPECIES RECORDED IN MALAYSIAN PEAT SWAMP FORESTS

Peat swamp forests have unique water quality and as a result, fish species that can survive and breed in the black water environment are limited. Researchers have reported many species of fish in PSFs that are not found in other habitats (Davies & Abdullah, 1989; Ng et al., 1994). A comprehensive list and a summary of the fish species of Malaysia PSFs are given in Tables 1 and 2.

North Selangor Peat Swamp Forest

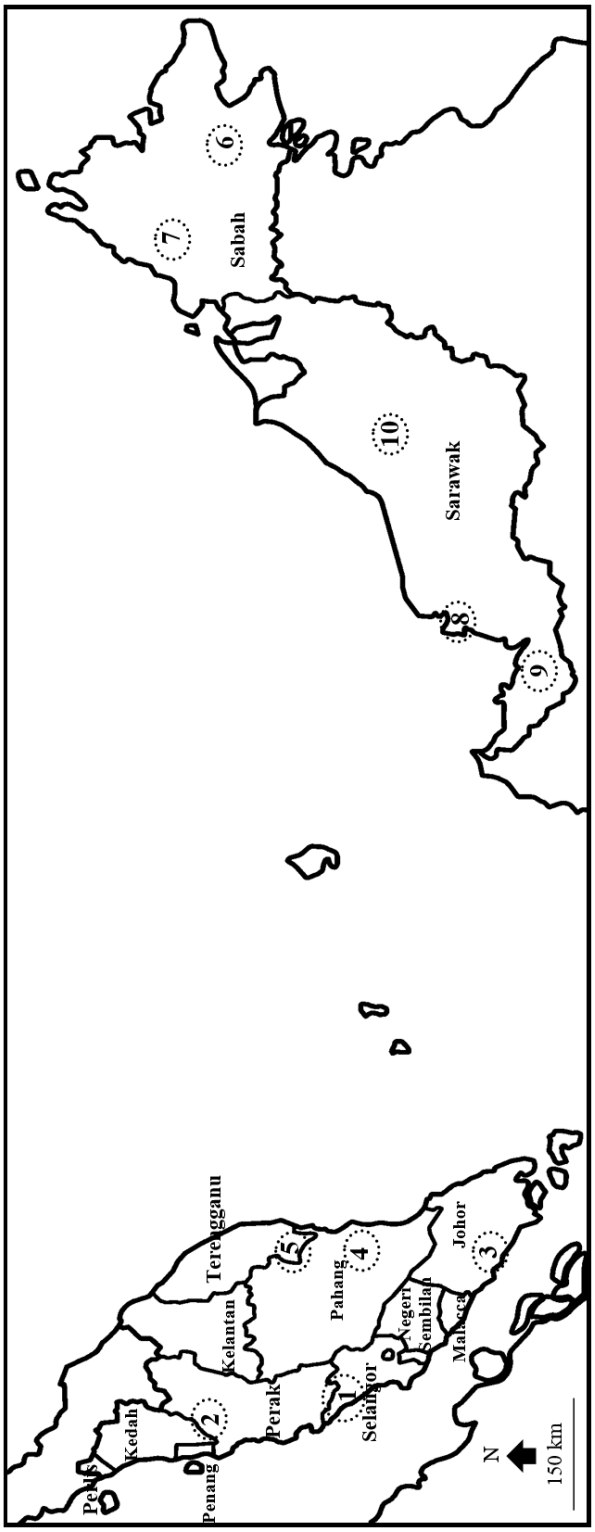
The NSPSF has been well studied relative to other PSFs in Malaysia. The most extensive surveys of the fish fauna of NSPSF were done by Davies and Abdullah (1989), IPT-AWB (1993), Ng et al. (1994), Beamish et al. (2003), Ahmad et al. (2013), Ismail et al. (2013) and Siow et al. (2013).

Davies and Abdullah (1989), in a survey of freshwater fish of NSPSF in 1989, recorded 42 fish species (actually 41 species, with the exception of *Osteochilus hasselti*, the synonym of *O. vittatus* recorded as another different species) belonging to 11 families (Table 1). A lot of scientific names, from family to species level, have been changed over the past decade. The most recent comprehensive list of such changes is outlined in Kottelat's catalogue of the fishes of Southeast Asia (Kottelat, 2013).

An intensive survey in 1992 by IPT-AWB (1993) recorded 76 fish species belonging to 24 families (23 with exception of Belontiidae, now included in the family Osphronemidae). This is one of the most successful surveys in NSPSF in terms of diversity. Ng et al. (1994) recorded 47 species of fish living in the black waters of NSPSF, and 14 species of the fishes were stenotopic to acidic black waters. Six unique fish species relatively new to science were first recorded at NSPSF in 1989 (Ng et al., 1994).

Studies by Beamish et al. (2003) conducted from 1997 to 1998 recorded 35 fish species from NSPSF belonging to 14 families (actually 13 because Belontiidae and Luciocephalidae which are now included in Osphronemidae, were recorded separately), while Giam et al. (2012) recorded eight blackwater fish species belonging to the six families from NSPSF.

Recently, during the Selangor Scientific and Biodiversity Peatland Expedition of 2013, Ahmad et al. (2013), Ismail et al. (2013) and Siow et al. (2013) recorded 30 species from 13 families, 41 species from 13 families, and 24 species 10 families, respectively. The comprehensive list of fish species recorded from NSPSF is given in Table 1.



Key:

1- North Selangor peat swamp forest (NSPSF), Selangor
2- Paya Beriah peat swamp forest (PBPSF), north Perak
3- Black water sites, west Johor
4- Southeast Pahang peat swamp forest (SEPPSF)
5- Black water sites, part of Pahang and Terengganu
6- Segama River, Sabah
7- Maliau basin, Sabah
8- Rajang basin, Sarawak
9- Black water sites, Batang Kerang and Sadong, Sarawak
10- Black water sites, Nanga Merit area, Sarawak

Figure 1. Location of PSFs and black water sites surveyed

Table 1
Checklist of black water fish in Malaysia

Family	Species	IUCN Status	NSPSF	PBPSF	Johor PSFs	SEPPSF	EP PSFs	Sabah PSFs	Sarawak PSFs	References
Akysidae	*Acrochordonichthys ischnosoma* Bleeker, 1858	NE	x							Davies & Abdullah, 1989
	Acrochordonichthys rogosus (Bleeker, 1846)	NE	x							IPT-AWB, 1993
	Akysis cf. *hendricksoni* Alfred, 1986	LC	x							IPT-AWB, 1993
	Parakysis verrucosus Herre, 1940	NE	x							IPT-AWB, 1993; Ng et al., 1994
Anabantidae	*Anabas testudineus* (Bloch, 1792)	DD	x	x		x			x	Davies & Abdullah, 1989; IPT-AWB, 1993; Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006; Khairul-Adha et al., 2009; Ahmad et al., 2013; Ismail et al., 2013; Siow et al., 2013
Anguillidae	*Anguilla borneensis* Popta, 1924	VU						x		Martin-Smith & Tan, 1998
Aplocheilidae	*Aplocheilus panchax* (Hamilton, 1822)	LC		x						Zakaria et al., 1999; Rezawaty, 2004; Shah et al., 2006
Ariidae	*Cryptarius truncatus* (Valenciennes, 1840)	NE						x		Martin-Smith & Tan, 1998
	Batrachocephalus mino (Hamilton, 1822)	NE						x		Martin-Smith & Tan, 1998
	Cephalocassis borneensis (Bleeker, 1851)	NE						x		Martin-Smith & Tan, 1998
Engraulididae	*Setipinna melanochir* (Bleeker, 1849)	NE						x		Martin-Smith & Tan, 1998

cont'd Table 1

Balitoridae	*Homaloptera* cf. *nebulosa* (Alfred, 1969)	NE	x			x			IPT-AWB, 1993; Ahmad et al., 2005
	Homaloptera ogilviei (Alred, 1967)	DD	x						IPT-AWB, 1993
	Homaloptera zollingeri (Bleeker, 153)	LC	x						IPT-AWB, 1993
	Neohomaloptera johorensis (Herre, 1944)	NE	x				x	x	Ng et al., 1994; Ng & Tan, 1999; Beamish et al., 2003; Giam et al., 2012; Ahmad et al., 2013
Barbuccidae	*Barbucca diabolica* Roberts, 1989	DD			x	x			Ahmad et al., 2005; Giam et al., 2012
Bagridae	*Bagrichthys hypselopterus* (Bleeker, 1852)	NE	x						Davies & Abdullah, 1989
	Bagrichthys macrocanthus (Bleeker, 1854)	NE	x						Siow et al., 2013
	Bagrichthys macropterus (Bleeker, 1854)	NE						x	Hassan et al., 2010
	Hemibagrus baramensis (Regan, 1906)	NE	x						Davies & Abdullah, 1989; Martin-Smith & Tan, 1998
	Hemibagrus capitulum (Popta, 1904)	NE				x			Ahmad et al., 2005
	Hemibagrus nemurus (Valenciennes, 1840)	LC	x	x			x	x	IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Khairul-Adha et al., 2009; Shah et al., 2006; Jimmy et al., 2010; Ismail et al., 2013; Siow et al., 2013
	Hemibagrus planiceps (Valenciennes, 1840)	NE						x	Hassan et al., 2010
	Hemibagrus sabanus (Inger & Chin, 1959)	NE					x		Martin-Smith & Tan, 1998

cont'd Table 1

	Hyalobagrus ornatus (Duncker, 1904)	NE			x	x			Ng & Kottelat, 1998; Ahmad et al., 2005; Giam et al., 2012
	Leiocassis leiacanthus (Weber & de Beaufort, 1912)	NE	x						Davies & Abdullah, 1989
	Leiocassis micropogon (Bleeker, 1852)	NE	x						Ng et al., 1994; Beamish et al., 2003
	Leiocassis poeciloptera (Valenciennes, 1840)	NE	x						Siow et al., 2013
	Leiocassis stenomus (Valenciennes, 1839)	NE	x						IPT-AWB, 1993
	Mystus bimaculatus (Volz, 1904)	NE	x						IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Giam et al., 2012; Ahmad et al., 2013; Ismail et al., 2013
	Mystus nigriceps (Valenciennes, 1840)	NE	x	x				x	Davies & Abdullah, 1989; IPT-AWB, 1993; Shah et al., 2006; Hassan et al., 2010; Ismail et al., 2013; Siow et al., 2013
	Pseudomystus robustus (Inger & Chin, 1959)	NE					x		Martin-Smith & Tan, 1998
Chacidae	*Chaca bankanensis* Bleeker, 1852	LC			x				Giam et al., 2012
Chaudhuriidae	*Bihunichthys monopteroides* (Kottelat & Lim, 1994)	NE	x						IPT-AWB, 1993; Ng et al., 1994
	Chendol keelini Kottelat & Lim, 1994	NE				x			Ahmad et al., 2005
	Nagaichthys filipes Kottelat & Lim, 1991	NE			x		x	x	Giam et al., 2012

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Channidae	*Channa bankanensis* (Bleeker, 1853)	NE	x		x	x		IPT-AWB, 1993; Ng et al., 1994; Martin-Smith & Tan, 1998; Beamish et al., 2003; Ahmad et al., 2005; Ahmad et al., 2013; Ismail et al., 2013
	Channa gachua (Hamilton, 1822)	LC	x					Ng et al., 1994
	Channa lucius (Cuvier, 1831)	LC	x	x	x		x	Davies & Abdullah, 1989; Ng et al., 1994; Zakaria et al., 1999; Beamish et al., 2003; Ahmad et al., 2005; Parenti & Lim, 2005; Shah et al., 2006; Khairul-Adha et al., 2009; Ahmad et al., 2013; Ismail et al., 2013
	Channa marulioides (Bleeker, 1851)	LC			x			Ahmad et al., 2005
	Channa melosoma (Bleeker, 1851)	LC	x					IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003
	Channa micropeltes (Cuvier, 1831)	LC	x		x			Davies & Abdullah, 1989; Ahmad et al., 2005
	Channa striata (Bloch, 1797)	LC	x	x	x			Davies & Abdullah, 1989; IPT-AWB, 1993; Beamish et al., 2003; Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006; Ahmad et al., 2013; Siow et al., 2013
	Channa sp.?	-		x				Shah et al., 2006
Cichlidae	**Oreochromis mossambicus* (Peters, 1852)	NT				x		Martin-Smith & Tan, 1998

cont'd Table 1

Clariidae	*Clarias batrachus* (Linnaeus, 1758)	LC	x				x	IPT-AWB, 1993; Khairul-Adha et al., 2009; Siow et al., 2013
	Clarias leiacanthus Bleeker, 1851	NE	x		x		x	Davies & Abdullah, 1989; Ng et al., 1994; Beamish et al., 2003; Ahmad et al., 2005; Khairul- Adha et al., 2009; Ahmad et al., 2013
	Clarias macrocephalus Günther, 1864	NT	x	x	x		x	Rezawaty, 2004; Ahmad et al., 2005; Khairul-Adha et al., 2009; Siow et al., 2013
	Clarias meladerma (Bleeker, 1846)	LC	x					Ng et al., 1994; Ismail et al., 2013
	Clarias nieuhofii (Valenciennes, 1840)	LC	x		x		x	IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Ahmad et al., 2005; Khairul-Adha et al., 2009; Ismail et al., 2013
	Encheloclarias baculum Ng & Lim, 1993	NE					x	Ng & Tan, 2000; Giam et al., 2012
	Encheloclarias curtisoma Ng & Lim, 1993	CR	x		x			IPT-AWB, 1993; Ng et al., 1994; Giam et al., 2012
	Encheloclarias kelioides Ng & Lim, 1993	CR				x		Giam et al., 2012
	Encheloclarias prolatus Ng & Lim, 1993	VU					x	Giam et al., 2012
Cobitidae	*Acanthopsoides molobrion* (Seibert, 1991)	LC	x					IPT-AWB, 1993
	Acantopsis cf. *dialuzona* (van Hasseltt, 1823)	LC	x	x				IPT-AWB, 1993; Rezawaty, 2004
	Kottelatlimia katik (Kottelat & Lim, 1992)	NE			x		x	Giam et al., 2012

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	Kottelatlimia pristes (Roberts, 1989)	NE	x				IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003
	Pangio kuhlii (Valenciennes, 1846)	NE	x				IPT-AWB, 1993
	Pangio muraeniformis (de Beaufort, 1933)	NE			x		Ahmad et al., 2005
	Pangio shelfordii (Popta, 1903)	NE			x		Ahmad et al., 2005
	Lepidocephalichthys tomaculum (Kottelat & Lim, 1992)	NE	x				Ng et al., 1994; Ahmad et al., 2013
Cyprinidae	*Boraras maculatus* (Duncker, 1904)	LC			x		Ahmad et al., 2005
	Barbodes banksi (Herre, 1940)	NE			x		Ahmad et al., 2005
	Barbodes sealei (Herre, 1933)	NE				x	Martin-Smith & Tan, 1998; Jimmy et al., 2010
	Barbonymus balleroides (Valenciennes, 1842)	NE				x	Martin-Smith & Tan, 1998
	Barbonymus gonionotus (Bleeker, 1949)	LC	x	x			Davies & Abdullah, 1989; Rezawaty, 2004; Siow et al., 2013
	Barbonymus schwanefeldii (Bleeker, 1854)	LC	x	x			Davies & Abdullah, 1989; IPT-AWB, 1993; Rezawaty, 2004; Ismail et al., 2013
	Brevibora cheeya (Liao & Tan, 2011)	NE	x				Ismail et al., 2013
	Crossocheilus cobitis (Bleeker, 1854)	NE				x	Martin-Smith & Tan, 1998
	Crossocheilus cf. *oblongus* (Kuhl & van Hasselt, 1823)	LC	x				IPT-AWB, 1993

cont'd Table 1

	Cyclocheilichthys apogon (Valenciennes, 1842)	LC	x	x		x			Davies & Abdullah, 1989; IPT-AWB, 1993; Zakaria et al., 1999; Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006; Ismail et al., 2013
	Cyclocheilichthys heteronema (Bleeker, 1853)	LC	x					x	IPT-AWB, 1993; Hassan et al., 2010
	Cyclocheilichthys repasson (Bleeker, 1853)	LC	x				x		IPT-AWB, 1993; Martin-Smith & Tan, 1998
	Desmopuntius hexazona (Weber & de Beaufort, 1912)	NE	x	x		x			IPT-AWB, 1993; Ng et al., 1994; Zakaria et al., 1999; Beamish et al., 2003; Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006; Ahmad et al., 2013; Ismail et al., 2013
	Desmopuntius johorensis (Duncker, 1904)	NE	x		x	x	x	x	IPT-AWB, 1993; Ng et al., 1994; Kottelat, 1996; Beamish et al., 2003; Ahmad et al., 2005; Parenti & Lim, 2005; Giam et al., 2012; Ahmad et al., 2013; Ismail et al., 2013; Siow et al., 2013
	Desmopuntius pentazona (Boulenger, 1894)	NE						x	Parenti & Lim, 2005
	Hampala macrolepidota (Kuhl & van Hasselt, 1823)	LC	x						Davies & Abdullah, 1989; IPT-AWB, 1993; Ismail et al., 2013
	Hampala sabana Inger & Chin, 1962	NE					x		Martin-Smith & Tan, 1998
	Hypophthalmichthys molitrix (Valenciennes, 1844)	NE		x					Rezawaty, 2004

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	Kottelatia brittani (Axelrod, 1976)	NE		x					Zakaria et al., 1999; Rezawaty, 2004
	Lobocheilos bo (Popta, 1904)	NE					x	x	Martin-Smith & Tan, 1998; Hassan et al., 2010
	***Labiobarbus leptocheilus* (Valenciennes, 1842)	LC	x	x					Davies & Abdullah, 1989; Rezawaty, 2004; Shah et al., 2006
	Labiobarbus sabanus (Inger & Chin, 1962)	NE					x		Martin-Smith & Tan, 1998
	Luciosoma pellegrinii Popta, 1905	NE					x		Martin-Smith & Tan, 1998
	Macrochirichthys macrochirus (Valenciennes, 1844)	NT	x						Davies & Abdullah, 1989
	Mystacoleucus marginatus (Valenciennes, 1842)	LC	x						Davies & Abdullah, 1989; IPT-AWB, 1993
	Nematabramis everetti Boulenger, 1894	NE					x		Martin-Smith & Tan, 1998; Sade & Biun, 2012
	Osteochilus chini Karnasuta, 1993	NE					x		Martin-Smith & Tan, 1998
	Osteochilus enneaporos (Bleeker, 1852)	LC	x						IPT-AWB, 1993
	Osteochilus ingeri Karnasuta, 1993	NE					x		Martin-Smith & Tan, 1998
	Osteochilus microcephalus (Valenciennes, 1842)	LC					x		Sade & Biun, 2012
	Osteochilus spilurus (Bleeker, 1851)	LC	x		x	x	x	x	Ng et al., 1994; Beamish et al., 2003; Ahmad et al., 2005; Giam et al., 2012
	Osteochilus vittatus (Valenciennes, 1842)	LC	x	x		x			Davies & Abdullah, 1989; IPT-AWB, 1993; Zakaria et al., 1999; Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006

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	Osteochilus enneaporos (Bleeker, 1852)	LC	x					IPT-AWB, 1993
	Oxygaster anomalura (van Hasselt, 1829)	LC	x	x			x	Davies & Abdullah, 1989; IPT-AWB, 1993; Shah et al., 2006; Khairul-Adha et al., 2009
	Paedocypris micromegethes Kottelat, Britz, Tan & Witte, 2006	NE					x	Giam et al., 2012
	Paedocypris sp. "North Selangor"	-	x					Giam et al., 2012
	Paedocypris sp. "Pahang"	-				x		Giam et al., 2012
	Parachela hypophthalmus (Bleeker, 1860)	LC			x			Ahmad et al., 2005
	Parachela oxygastroides (Bleeker, 1852)	LC	x					Davies & Abdullah, 1989; IPT-AWB, 1993; Ismail et al., 2013
	Puntioplites bulu (Bleeker, 1851)	DD	x					Davies & Abdullah, 1989; IPT-AWB., 1993; Martin-Smith & Tan, 1998
	Puntius binotatus (Valenciennes, 1842)	LC	x	x				Davies & Abdullah, 1989; Rezawaty, 2004; Shah et al., 2006
	Puntius fasciatus (Jerdon, 1849)	LC	x					Davies & Abdullah, 1989
	Puntigrus partipentazona (Fowler, 1934)	LC			x			Ahmad et al., 2005
	Rasbora argyrotaenia (Bleeker, 1849)	NE					x	Martin-Smith & Tan, 1998
	Rasbora bankanensis (Bleeker, 1853)	NE	x		x			IPT-AWB, 1993; Ahmad et al., 2005
	Rasbora borapetensis Smith, 1934	LC		x				Rezawaty, 2004

cont'd Table 1

	Rasbora cf. *sumatrana* (Bleeker, 1852)	NE	x	x		x	Davies & Abdullah, 1989; IPT-AWB, 1993; Zakaria et al., 1999; Rezawaty, 2004; Shah et al., 2006; Sade & Biun, 2012; Siow et al., 2013
	Rasbora dorsiocellata (Duncker, 1904)	NE	x		x		Ng et al., 1994; Ahmad et al., 2005
	Rasbora maculata (Duncker, 1904)	NE	x				IPT-AWB, 1993; Ng et al., 1994
	Rasbora gracilis (Kottelat, 1991)	NE	x		x		IPT-AWB, 1993; Beamish et al., 2003; Ahmad et al., 2005
	Rasbora kalochroma (Bleeker, 1851)	NE	x		x		Davies & Abdullah, 1989; IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Ahmad et al., 2005; Ahmad et al., 2013; Ismail et al., 2013; Siow et al., 2013
	Rasbora cephalotaenia (Bleeker, 1852)	NE	x	x	x		Davies & Abdullah, 1989; IPT-AWB, 1993; Ng et al., 1994; Zakaria et al., 1999; Beamish et al., 2003; Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006; Ahmad et al., 2013; Ismail et al., 2013
	Rasbora dusonensis (Bleeker, 1850)	NE	x				IPT-AWB, 1993; Ismail et al., 2013
	Rasbora einthovenii (Bleeker, 1851)	NE	x		x		IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Ahmad et al., 2005; Ahmad et al., 2013; Ismail et al., 2013

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	Rasbora elegans Volz, 1903	LC			x			Ahmad et al., 2005
	Rasbora paucisqualis Ahl, 1935	LC			x			Ahmad et al., 2005
	Rasbora tornieri Ahl, 1922	LC					x	Parenti & Lim, 2005
	Rasbora trilineata Steindachner, 1870	LC		x	x			Zakaria et al., 1999; Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006
	Striuntius lineatus (Duncker, 1904)	NE	x	x				Zakaria et al., 1999; Rezawaty, 2004; Shah et al., 2006; Ismail et al., 2013
	Sundadanio margarition Conway, Kottelat & Tan, 2011	NE					x	Giam et al., 2012
	Thynnichthys thynnoides (Valenciennes, 1842)	LC	x					Davies & Abdullah, 1989
	Trigonopoma pauciperforatum (Weber & de Beaufort, 1916)	NE	x	x	x		x	IPT-AWB, 1993; Ng et al., 1994; Zakaria et al., 1999 ; Ahmad et al., 2005; Khairul Adha et al., 2009; Ahmad et al., 2013; Ismail et al., 2013
	Trigonopoma gracile (Kottelat, 1991)	NE	x					Ismail et al., 2013; Siow et al., 2013
	Trigonostigma heteromorpha (Ducker, 1904)	LC	x	x	x			IPT-AWB, 1993; Zakaria et al., 1999; Ahmad et al., 2005
Eleotrididae	*Oxyeleotris marmorata* (Bleeker, 1852)	NE	x	x				Davies & Abdullah, 1989; IPT-AWB, 1993; Rezawaty, 2004
Gobiidae	*Gobiid* sp.	-				x		Martin-Smith & Tan, 1998
	Pseudobiopsis oligactis (Bleeker, 1875)	NE	x					IPT-AWB, 1993

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Helostomatidae	*Helostoma temminkii* (Cuvier, 1829)	LC	x	x	x	x	IPT-AWB, 1993; Ng et al., 1994; Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006; Khairul-Adha et al., 2009; Ahmad et al., 2013; Ismail et al., 2013; Siow et al., 2013
Mastacembelidae	*Macrognathus aculeatus* (Bloch, 1787)	NE	x				IPT-AWB, 1993
	Macrognathus circumcinctus (Hora, 1924)	LC	x				IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Ahmad et al., 2013; Ismail et al., 2013
	Mastacembelus armatus (La Cepède, 1800)	LC		x			Shah et al., 2006
Nandidae	*Nandus nebulosus* (Gray, 1835)	LC	x	x	x		IPT-AWB, 1993; Ng et al., 1994; Zakaria et al., 1999; Beamish et al., 2003; Ahmad et al., 2005; Ahmad et al., 2013
Nemacheilidae	*Nemacheilus selangoricus* (Duncker, 1904)	DD	x	x	x		Ahmad et al., 2005; Zakaria et al., 1999; Beamish et al., 2003; Ismail et al., 2013
Notopteridae	*Chitala chitala* (Hamilton, 1822)	NT	x				Davies & Abdullah, 1989
	Chitala lopis (Bleeker, 1851)	LC	x	x	x		IPT-AWB, 1993; Ahmad et al., 2005; Shah et al., 2006
	Notopterus notopterus (Pallas, 1976)	LC	x	x			Davies & Abdullah, 1989; Rezawaty, 2004; Shah et al., 2006; Ismail et al., 2013

cont'd Table 1

Osphronemidae	*Belontia hasselti* (Cuvier, 1831)	NE	x	x		x		Davies & Abdullah, 1989; IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006; Ahmad et al., 2013; Ismail et al., 2013
	Betta akarensis Regan, 1910	NE					x	Parenti & Lim, 2005
	Betta bellica (Sauvage, 1884)	LC	x			x		IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Ahmad et al., 2005; Ahmad et al., 2013; Ismail et al., 2013
	Betta brownorum Witte & Schmidt, 1992	NE					x	Giam et al., 2012
	Betta hipposideros Ng & Kottelat, 1994	VU	x					Ng et al., 1994; Ahmad et al., 2013; Ismail et al., 2013
	Betta ibanorum Tan & Ng, 2004	NE					x	Giam et al., 2012
	Betta livida (Ng & Kottelat, 1992)	EN	x					IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Giam et al., 2012; Ahmad et al., 2013; Ismail et al., 2013
	Betta imbellis (Ladiges, 1975)	LC	x					IPT-AWB, 1993
	Betta persephone Schaller, 1986	CR			x			Giam et al., 2012
	Betta pugnax (Cantor, 1849)	NE	x	x				Davies & Abdullah, 1989; Zakaria et al., 1999; Beamish et al., 2003; Ismail et al., 2013; Siow et al., 2013
	Betta pulchra Tan & Tan, 1996	NE			x			Giam et al., 2012
	Betta splendens Regan, 1910	VU		x				Rezawaty, 2004; Shah et al., 2006

cont'd Table 1

	Betta taeniata Regan, 1910	NE		x				Rezawaty, 2004
	Betta tomi Ng & Kottelat, 1994	VU			x			Giam et al., 2012
	Betta tussyae Schaller, 1985	NE				x	x	Ahmad et al., 2005; Giam et al., 2012
	Betta waseri (Krummenacher, 1987)	NE	x			x	x	IPT-AWB, 1993; Ahmad et al., 2005; Giam et al., 2012
	Luciocephalus pulcher (Gray, 1830)	NE	x	x		x	x	Davies & Abdullah, 1989; IPT-AWB, 1993; Ng et al., 1994; Zakaria et al., 1999; Beamish et al., 2003; Ahmad et al., 2005; Parenti & Lim, 2005; Ahmad et al., 2013; Ismail et al., 2013; Siow et al., 2013
	Osphronemus goramy La Cepède, 1801	LC		x				Rezawaty, 2004
	Parosphromenus alfredi Kottelat & Ng, 2005	NE			x			Giam et al., 2012
	Parosphromenus allani Brown, 1987	NE					x	Giam et al., 2012
	Parosphromenus filamentosus Vierke, 1981	NE		x				Zakaria et al., 1999
	Parosphromenus harveyi (Brown, 1987)	EN	x					IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Giam et al., 2012; Ahmad et al., 2013; Ismail et al., 2013
	Parosphromenus nagyi Schaller, 1985	NE				x	x	Ahmad et al., 2005; Giam et al., 2012
	Parosphromenus tweediei Kottelat & Ng, 2005	NE			x			Giam et al., 2012

cont'd Table 1

	Sphaerichthys osphromenoides (Canestrini, 1860)	NE	x	x	x			IPT-AWB, 1993; Ng et al., 1994; Zakaria et al., 1999; Beamish et al., 2003; Rezawaty, 2004; Ahmad et al., 2005; Ahmad et al., 2013; Ismail et al., 2013; Siow et al., 2013
	Trichopodus leerii (Bleeker, 1852)	NT	x		x			Davies & Abdullah, 1989; IPT-AWB, 1993; Ng et al., 1994; Ahmad et al., 2005; Ahmad et al., 2013; Ismail et al., 2013
	Trichopodus pectoralis (Regan, 1910)	LC	x	x			x	IPT-AWB, 1993; Ng et al., 1994; Rezawaty, 2004; Shah et al., 2006; Khairul-Adha et al., 2009
	Trichopodus trichopterus (Pallas, 1770)	LC	x	x	x	x	x	IPT-AWB, 1993; Ng et al., 1994; Martin-Smith & Tan, 1998; Beamish et al., 2003; Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006; Khairul-Adha et al., 2009; Ahmad et al., 2013; Ismail et al., 2013; Siow et al., 2013
	Trichopsis vittata (Cuvier, 1831)	LC	x		x			IPT-AWB, 1993; Ng et al., 1994; Ahmad et al., 2005; Ahmad et al., 2013; Ismail et al., 2013; Siow et al., 2013
Pangasiidae	*Pangasius lithostoma* Roberts, 1989	NE					x	Hassan et al., 2010
	Pseudolais micronemus (Bleeker, 1846)	DD			x	x		Martin-Smith & Tan, 1998; Ahmad et al., 2005

cont'd Table 1

Pristolepididae	*Pristolepis grootii* (Bleeker 1852)	NE	x					IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Ismail et al., 2013
	Pristolepis fasciata (Bleeker, 1851)	LC	x	x	x			Rezawaty, 2004; Ahmad et al., 2005; Shah et al., 2006; Siow et al., 2013
Siluridae	*Kryptopterus bircirrhis* (Valenciennes, 1839)	LC	x					Davies & Abdullah, 1989; IPT-AWB, 1993
	Kryptopterus limpok (Bleeker, 1852)	NE					x	Hassan et al., 2010
	Kryptopterus macrocephalus (Bleeker, 1858)	LC	x		x			Davies & Abdullah, 1989; IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Ahmad et al., 2005; Ahmad et al., 2013; Ismail et al., 2013
	Kryptopterus sp.?	-	x					Siow et al., 2013
	Ompok bimaculatus (Bloch, 1794)	NT	x	x				Davies & Abdullah, 1989; Shah et al., 2006
	Ompok fumidus (Tan & Ng, 1996)	VU	x					Beamish et al., 2003; Siow et al., 2013
	Ompok leiacanthus (Bleeker, 1853)	DD	x					IPT-AWB, 1993; Ng et al., 1994
	Ompok sabanus Inger & Chin, 1959	NE				x		Martin-Smith & Tan, 1998
	Ompok sp.?	-		x				Zakaria et al., 1999; Shah et al., 2006
	Phalacronotus apogon (Bleeker, 1851)	LC			x			Ahmad et al., 2005
	Phalacronotus parvanalis (Inger & Chin, 1959)	NE				x		Martin-Smith & Tan, 1998

cont'd Table 1

	Silurichthys hasseltii (Bleeker, 1858)	NE	x		x			IPT-AWB, 1993; Ng et al., 1994; Ahmad et al., 2005
	Silurichthys indragiriensis (Volz, 1904)	NE	x					Beamish et al., 2003; Giam et al., 2012; Ahmad et al., 2013; Ismail et al., 2013
	Silurichthys phaiosoma (Bleeker, 1851)	NE					x	Giam et al., 2012
	Wallago leeri Bleeker, 1851	NE	x		x			Ahmad et al., 2005; Siow et al., 2013
	Wallago maculatus Inger & Chin, 1859	NE				x		Martin-Smith & Tan, 1998
Symbranchidae	*Monopterus albus* (Zuiew, 1793)	LC	x	x	x			IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Ahmad et al., 2005; Shah et al., 2006; Siow et al., 2013
Syngnathidae	*Doryichthys deokhatoides* (Bleeker, 1854)	NE	x					IPT-AWB, 1993
	Doryichthys martensii (Peters, 168)	NE	x					IPT-AWB, 1993
Tetraodontidae	*Pao leirus* (Bleeker, 1850)	NE	x					Davies & Abdullah, 1989
Toxotidae	*Toxotes chatareus* (Hamilton, 1822)	NE				x		Martin-Smith & Tan, 1998
Zenarchopteridae	*Dermogenys pusilla* Kuhl & van Hasselt, 1823	NE		x				Shah et al., 2006
	Hemirhamphodon byssus Tan & Lim, 2013	NE					x	Hassan et al., 2010
	Hemirhamphodon kapuasensis Collett, 1991	NE					x	Hassan et al., 2010
	Hemirhamphodon kuekenthali Steindachner, 1901	NE					x	Hassan et al., 2010
	Hemirhamphodon phaiosoma (Bleeker, 1852)	NE					x	Hassan et al., 2010

cont'd Table 1

	Hemirhamphodon pogonognathus (Bleeker, 1853)	LC	x	x	x	IPT-AWB, 1993; Ng et al., 1994; Zakaria et al., 1999; Beamish et al., 2003; Rezawaty, 2004; Ahmad et al., 2005; Ahmad et al., 2013; Ismail et al., 2013

* Introduced species
**Confusing taxonomy
IUCN Status source: IUCN, (2015)
NE = Not Evaluated, DD = Data Deficient, LC = Least Concern, NT = Near Threatened, VU = Vulnerable, EN = Endangered, CR = Critically Endangered, EW = Extinct in the Wild, EX = Extinct
NSPSF = North Selangor peat swamp forest, PBPSF = Paya Beriah peat swamp forest, SEPPSF = Southeast Pahang peat swamp forest, EP = East Peninsular Malaysia (part of Pahang and Terengganu), PSFs = Peat Swamp Forests

Table 2
Summary of black water fish species recorded in Malaysia

Peat swamp sites	Location	Region	No. of families	No. of species	Reference
NSPSF	Selangor	Peninsular Malaysia	23	114	Davies & Abdullah, 1989; IPT-AWB, 1993; Beamish et al., 2003; Ahmad et al., 2013; Ismail et al., 2013; Siow et al., 2013
PBPSF	Perak	Peninsular Malaysia	18	49	Zakaria et al., 1999; Rezawaty, 2004; Shah et al., 2006
Black water ditches and ponds of west Johor and Ambat	Johor	Peninsular Malaysia	7	13	Kottelat, 1996; Ng & Kottelat, 1998; Giam et al., 2012
SEPPSF	Pahang	Peninsular Malaysia	19	58	Ahmad et al., 2005
Endau drainage, black water sites including ponds and ditches	Pahang and Terengganu	Peninsular Malaysia	5	9	Kottelat, 1996; Ng & Tan, 1999; Giam et al., 2012
Segama River, Maliau Basin	Sabah	Malaysia Borneo	12	31	Martin-Smith & Tan, 1998; Sade & Biun, 2012
Rajang Basin, Sadong, Batang Kerang, Nanga Merit	Sarawak	Malaysia Borneo	13	40	Parenti & Lim, 2005; Khairul-Adha et al., 2009; Hassan et al., 2010; Giam et al., 2012; Tan & Lim, 2013

Paya Beriah Peat Swamp Forest, North Perak

The Paya Beriah peat swamp forest (PBPSF), which is located near Bukit Merah reservoir, Perak, has a total area of 5,500 hectares that are bordered by dykes, roads and railway tracks. Like most PSFs in Malaysia, it has been significantly impacted through conversion to residential, industrial and agricultural uses (Ismail & Ali, 2002). Nonetheless, the fish population and its biodiversity in PBPSF are not well documented, in comparison with NSPSF. The most recognised and well-documented surveys in PBPSF were done by Zakaria et al. (1999), Rezawaty (2004) and Shah et al. (2006).

Zakaria et al. (1999) conducted a study of the swamp-riverine fish populations of two spatially isolated fresh water swamp ecosystems: Beriah Kiri River, which was mistakenly identified as Beriah Kanan River (Shah et al., 2006), located in northern Peninsular Malaysia, and the Ulu Sedili River in southern Peninsular Malaysia. The Beriah Kiri and Ulu Sedili river systems are separated by an extensive mountain

range and a north-south distance of about 900 km, creating an effective dispersal and/or migration barrier (Johnson, 1967a; Prentice & Parish, 1992; Krebs, 2009). Zakaria et al. (1999) reported a total of 24 fish species identified from their study, of which 20 species were from Beriah Kiri and 10 species from Ulu Sedili swamp-riverine area. Eight families were represented from the Beriah Kiri swamp-riverine area. However, only the fish species recorded from the Beriah Kiri swamp-riverine are outlined in this review.

A study from Rezawaty (2004) reported a total of 30 fish species from 12 families in a study carried out on the entire Sungai Beriah drainage system, while during an intensive survey of the PBPSF, specifically in Beriah Kanan, Beriah Kiri and Beriah rivers, Shah et al. (2006) recorded a total of 32 fish species belonging to 13 families (Table 1).

Fishes Recorded from the Peat Swamps of Johor

Information on the ichthyofauna of PSFs of the state of Johor is relatively patchy compared to the NSPSF. Kottelat (1996) and Ng and Kottelat (1998) recorded *Systomus lineatus* and *Hyalobagrus ornatus* respectively from PSF of Johor. Giam et al. (2012) recorded 13 fish species belonging to seven families from black water ditches, streams, pools, remnants of PSF and PSFs of West Johor and Ambat (Table 1).

Fishes Recorded from Southeast Pahang Peat Swamp Forest

Ahmad et al. (2005) recorded 58 fish species (with an additional unidentified species belonging to the family Mastacembelidae) from 17 families (19 following the recent taxonomic revisions detailed in Kottelat's catalogue) during a survey in Bebar River, a large river that flows out of the southeast Pahang peat swamp forest (SEPPSF, which is also known as Pekan peat swamp forest). This survey, which was conducted along Bebar River and Serai River (a tributary of Bebar River), brought the total fish species known in SEPPSF to 65 species (see Ahmad et al., 2005) (see Table 1).

Fishes Recorded from the Peat Swamps of East Peninsular Malaysia

Kottelat (1996) and Ng and Tan (1999) recorded *S. lineatus* and *Neohomaloptera johorensis* respectively from east Peninsular Malaysia. Similarly, Giam et al. (2012) recorded nine fish species from six families from the black waters of east Peninsular Malaysia comprising of part of Malaysia's Johor, Pahang and Terengganu (Table 1).

Fish Species Recorded in the Peat Swamp Forests of Sabah

Sabah, together with Sarawak, Kalimantan Barat, Kalimantan Timur and Brunei is situated in Borneo, the world's third largest island with some 743,107 km^2 of land area. As a result of "…difficulties of access to the interior part of tropical rainforest, a

lack of reliable dating of igneous rocks, poorly fossiliferous sedimentary rocks and an absence of a coherent stratigraphic scheme for many parts of the island" (Hall & Nichols, 2002), there is only fragmentary information on the geology and fish fauna of the island (Parenti & Lim, 2005). The fish species of Sabah are relatively less surveyed and documented than those of Peninsular Malaysia. Even when intensive surveys are carried out, they have not been widely published by the researchers.

Martin-Smith and Tan (1998) carried out an intensive collection of freshwater fishes over a period of two years from the catchment of the upper Segama River near Danum Valley Field Centre, headwater streams in the catchment of the Kuamut River and from the lower Segama River. They reported a total of 65 species from 20 families. A total of about 30 fish species were recorded in blackwater ditches, ponds and streams from the lower Segama River (Martin-Smith & Tan, 1998).

Also, Sade and Biun (2012) studied the ichthyofauna of Maliau Basin, a saucer-shaped depression enclosed by a mountainous rim in the remote part of Sabah, with an undisturbed flora and fauna. Although 15 fish species were recorded from the study, only three species were recorded from acidic tea-coloured blackwaters in the zone (Table 1).

Fish Species Recorded in the Peat Swamp Forests of Sarawak

Like Sabah, the ichthyofauna of the peat swamps of Sarawak has received little attention in comparison to that of Peninsular Malaysia. The ichthyofauna of Sarawak is generally neglected in comparison to the other political divisions of Borneo for which detailed checklists have been documented (Parenti & Lim, 2005).

Parenti and Lim (2005) carried out a study of the ichthyofauna of the Rajang Basin in Sarawak, Malaysia, Borneo, and presented a checklist of 164 fish species recorded from the headwaters all the way to the brackish waters, including Belaga and the Balui River, Kapit and the Baleh River, and Sibu area. A total of seven blackwater fish species were recorded from blackwater ditches and pools along Teku River and remnant of PSF behind the old Sibu airport.

A previous study from Khairul-Adha et al. (2009) recorded 36 species of fish belonging to 13 families from brownish and blackish water habitats of Batang Kerang in Balai Ringin, Sarawak, during wet and relatively dry seasons. Thirty-two species from 12 families were recorded in the brownish water, while only 12 species from seven families were recorded in the black water habitat. In a study by Hassan et al. (2010), seven out of 15 fish species recorded from 11 families in Nanga Merit area were from a water body with peat-like characteristics.

Recently, Tan and Lim (2013) recorded four species of fish of the genus *Hemirhamphodon* from blackwater ditches and ponds in Sarawak, Malaysia, Borneo, while Giam et al. (2012) recorded 13 fish species belonging to five families from the peat swamps of Rajang and Sadong in Sarawak (Table 1).

TAXONOMIC NOTES

Some of the taxonomic names of the fish species outlined in Table 1 and their placement within families are slightly or completely different from the originally recorded names from the surveys, as a result of the recent changes in the taxonomy of the fish species. A comprehensive list of taxonomic changes is given in Kottelat's catalogue (Kottelat, 2013). Davies and Abdullah (1989) recorded *O. vittatus*, along with its synonym *O. hasselti*, as two completely different species. The species *Belontia hasselti* now classified under the family Osphronemidae was placed in the Anabantidae family. Members of Osphronemidae family were placed in the family Belontia by IPT-AWB (1993) and Ng et al. (1994). In the same vein, *Luciocephalus pulcher* was classified under the family Luciocephalidae. Following the work of Britz (1994), and Kottelat and Whitten (1996), the earlier families of Osphronemidae, Belontiidae and Luciocephalidae were constituted as a single family, Osphronemidae. Recently, Beamish et al. (2003) classified *Nemacheilus selangoricus* under the family Nemacheiliidae in the family Bagridae, along with *N. johorensis*. In the same vein, Ahmad et al. (2005) classified *N. selangoricus* of the family Nemacheilidae and *Barbucca diabolica* of the family Barbuccidae under the family Balitoridae. Meanwhile, *Hemirhamphodon progonognathus* of the family Zenarchopteridae was placed in the family Hemiramphidae by IPT-AWB (1993), Ng et al. (1994), Beamish et al. (2003) and Ahmad et al. (2005). The *Parakysis verucosus* of the family Akysidae was also classified under Parakysidae by IPT-AWB (1993) and Ng et al. (1994), while Siow et al. (2013) recorded *Pristolepis fasciata* of the family Pristolepididae as belonging to the family Nandidae. Also, a recorded fish species belonging to the genus *Kryptopterus* was not designated a species name and the reason was not stated appropriately. Considering there are about 17 distinct species in the genus *Krptopterus* (Kottelat, 2013), it is possible that the sample could be a newly discovered species.

The species recorded as *Puntius lineatus* is now named *Striuntius lineatus,* which is a "preferred" name or "authority", the latter being a synonym. Another species recorded as *Labiobarbus lineatus*, which is excluded from Kottelat's catalogue was regarded as a preferred name for the species *Dangila lineata* in Fish Base, Species 200 and ITIS Catalogue of Life: April 2013, and the NCBI Taxonomy (Torrres, 2000; EOL, 2015). *Dangila lineata* was also recorded as a synonym of *L. leptocheilus* in Kottelat's catalogue (Kottelat, 2013), suggesting that both names may actually be referring to the same species. However, Rainboth et al. (2012) considered that *L. lineatus* is a distinct species. There has been some confusion about the taxonomy of the species *L. leptocheilus* (*L. lineatus*). In the taxonomic outline provided in this review, the species is presented as *L. leptocheilus* in line with Kottelat's catalogue. Also, the fish earlier recorded as *Mystus micracanthus* is actually *M. nigriceps* (Roberts, 1993; Ng, 2002; Kottelat, 2013).

ECONOMIC IMPORTANCE OF PEAT SWAMP FISHES

Black water peat swamps are important catchment areas. The peat has great water retention ability and serves as reservoir of rain water, which is utilised in agriculture for irrigating the rice fields adjacent the NSPSF (Low & Balamurugan, 1989). The fish of NSPSF are harvested for consumption and also for the aquarium trade due to their ornamental value (Ng et al*.,* 1994; Ismail et al*.,* 2013) (Table 4). Most of the species harvested for consumption by the local people are sold at very low prices relative to their actual worth (Ng et al*.,* 1994).

A breeding study has been carried out on some of the ornamental fish of peat black water such as pearl gourami (*Trichogaster leeri*), chocolate gourami (*Sphaerichthys osphromenoides*), clown rasbora (*Rasbora kalochroma*), six-banded barb (*P. johorensis*), bellicose Betta (*Betta bellica*), giant fighting fish (*B. waseri*) and pygmy rasbora (*R. maculata*), with the aim of conserving the species and improving their production (FFRC, 1995).

CONSERVATION STATUS OF PEAT SWAMP FISH SPECIES IN MALAYSIA

The conservation status of a species indicates if it still exists and how likely it is to become extinct in the near future (InfoNatura, 2007). The IUCN Red List of Threatened Species is the best known conservation status listing system in the world, which classifies species into nine categories based on the rate of decline of the population, population size, geographical range, and degree of population and distribution fragmentation (Mace et al*.,* 2008; Biodic, 2013; IUCN, 2014). The categories are "Extinct (EX), Extinct in the Wild (EW), Critically Endangered (CR), Endangered (EN), Vulnerable (VU), Near Threatened (NT), Least Concern (LC), Data Deficient (DD) and Not Evaluated (NE)" (IUCN, 2001; InfoNatura, 2007; IUCN, 2012; IUCN, 2015; IUCN, 2014). A species is EX when there is no reasonable doubt that the last individual has died, as a result of failure to record an individual through exhaustive surveys in known and/ or expected habitat, at appropriate times (diurnal, seasonal, annual), throughout its historic range. Extinct in the Wild is used to refer to species that are known only to survive in cultivation, in captivity or as a naturalised population(s) well outside the past range (InfoNatura, 2007; Biodic, 2013; IUCN, 2014).

Out of the 198 black water fish species recorded from Malaysia, 106 (53.54%) species belonging to the category NE indicate that their conservation status has not been evaluated against the criteria. Seven (3.53%) species are DD as a result of inadequate information on their distribution and/or population status. Sixty-two species (31.31%) belonging to the LC category, indicate lowest risk, widespread and abundant species. Six species (3.03%) are NT, signifying likelihood to become endangered in the future. Six (3.03%) and two (1.01%) species are VU and EN, respectively, indicating a highly and very highly risk of extinction in the wild. Besides that, three species (1.52%) are CR and

facing an extremely high risk of extinction in the wild, while six species (3.03%) were not fully classified and so exempted from all the categories (Table 1).

A total of only 12 species (6.70%) are threatened, i.e. under CR, EN and VU category. The IUCN classification may not be a true expression of the conservation status of black water fishes, particularly in Malaysia as so many of the species (57.54%) remain unevaluated against the criteria for classification of threatened species. In data-poor situations, it is not uncommon for listing errors of species that otherwise should be classified as threatened (Gärdenfors, 2000; Keith et al., 2000; Gärdenfors et al., 2001; Keith et al., 2004). For instance, five of the ten black water fish species (*B. brownorum, Sundadanio margarition, B. ibanorum, Parosphromenus allani* and *H. ornatus*), listed as "most VU" by Giam et al., (2012) using the criteria of decline in population, geographical range and basin extinction, were classified under the NE in Red List category (Tables 1 and 3).

It is important to point out that the species recorded as 'rare' at a distinct time may be more abundant at other times. For example, the abundance of individual fish and species composition vary during the wet and dry seasons, which may be related to variations in migratory movements of fish species (Ng et al., 1994; Renato et al., 2000; Khairul-Adha et al., 2009). Some species migrate from downstream to upper reaches of a river during high water levels for breeding or food, then migrate back to the lower reaches after spawning as the water level reduces (Lowe-McConnell, 1975; Welcomme, 1979). Therefore, conservation surveys should be exhaustive, in all known and/or expected habitats, at appropriate times covering seasons of high and low water levels over an extended period of time before a species is pronounced as rare or threatened.

Considering the extensive destruction of tropical PSFs worldwide and the decline in PSF biodiversity, more black water fish species will fall into the threatened (CR, EN and VU) category if evaluated against the criteria. However, it is important to note that the category of threat simply provides an assessment of the extinction risk under current circumstances, and is not necessarily sufficient to determine priorities for conservation action (Mace & Lande, 1991).

CONSERVATION OF PEAT SWAMP FORESTS

Peat swamp forests are an important component of the world's wetlands, providing a wide variety of goods and services in the form of carbon sequestration, flood mitigation and globally important biodiversity reservoirs (Parish, 2002; UNDP, 2006; Posa et al., 2011; Ismail et al., 2013), with many endemic species (Kottelat & Ng, 2005; Kottelat & Widjanarti, 2005; UNDP, 2006; Tan & Kottelat, 2009; Conway et al., 2011; Conway & Kottelat, 2011; Posa et al., 2011; Giam et al., 2012; Taskforce REDD, 2012; PIU-SERT, 2013; Muchlisin et al., 2015).

Malaysian PSFs make up about 75% of the country's total wetlands, with 80%

Table 3
Peat swamp fishes listed as Threatened in IUCN Red List

Family	Species	Status	Reference
Anguillidae	*Anguilla borneensis*	VU	Martin-Smith & Tan, 1998
Clariidae	*Encheloclarias curtisoma*	CR	IPT-AWB, 1993; Ng et al., 1994; Giam et al., 2012
	Encheloclarias keliodes	CR	Giam et al., 2012
	Encheloclarias prolatus	VU	Giam et al., 2012
Osphronemidae	*Ompok fumidus*	VU	Beamish et al., 2003; Siow et al., 2013
	Betta hipposideros	VU	Ng et al., 1994; Ahmad et al., 2013; Ismail et al., 2013
	Betta livida	EN	IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Giam et al., 2012; Ahmad et al., 2013; Ismail et al., 2013
	Betta splendens	VU	Rezawaty, 2004; Shah et al., 2006
	Betta tomi	VU	Giam et al., 2012
	Betta persephone	CR	Giam et al., 2012
	Parosphronemus harveyi	EN	IPT-AWB, 1993; Ng et al., 1994; Beamish et al., 2003; Giam et al., 2012; Ahmad et al., 2013; Ismail et al., 2013

found in east Malaysia (Sabah 8%; Sarawak 72%) and 20% in Peninsular Malaysia. Peat swamp forests in Malaysia have undergone severe degradation over the years. For example, the PSF cover of NSPSF was estimated to be 0.67 million hectares in 1981 but reduced drastically to 0.34 million hectares in the 1990s (UNDP, 2006) and there has been further destruction since then. As the nation becomes aware of the need to conserve PSFs, some percentage of PSFs have been protected within Permanent Forest Reserves and stateland forests (UNDP, 2006). However, this protection is inadequate. Agricultural conversion and fire have destroyed PSF within these protected areas and furthermore, unless the entire forests are protected, any drainage around the edges impacts the entire forest.

The main threats of PSFs in Malaysia are forestry (overexploitation), illegal logging, pollution (including oil, industrial, nutrient and sedimentation), waste disposal, airports, land reclamation, large scale land conversion for agriculture, industrialisation and settlement-urbanisation (Ng & Shamsudin, 2001; Chong et al*.,* 2010). In addition, draining and clearing of the PSFs for agriculture and palm oil plantations have resulted in peat land fires (Parish, 2002; Page et al*.,* 2011), which contribute to the annually recurring episodes of transboundary haze pollution in the Southeast Asian region (Lo & Parish, 2013).

Several studies on the diversity of fish in PSFs have revealed the existence of economically important fishes for consumption, aquarium trade and

Table 4
Commonly consumed and ornamental black water fish species in Malaysia

Consume	Ornamental
Anabas testudineus	*Betta bellica*
Belontia hasselti	*Betta livida*
Channa bankanensis	*Betta hipposideros*
Channa lucius	*Belontia hasselti*
Channa melosoma	*Channa gachua*
Clarias meladerma	*Helostoma temminkii*
Clarias nieuhofii	*Hemirhamphodon progonognathus*
Clarias leiacanthus	*Krvptopterus macrocephalus*
Helostoma temminkii	*Leiocassis micropogon*
Kryptopterus macrocephalus	*Luciocephalus pulcher*
Monopterus albus	*Macrognathus circumcinctus*
Mystus bimaculatus	*Mystus bimaculatus*
Macrognathus circumcinctus	*Osteochilus spilurus*
Hemibagrus nemurus	*Parosphromenus harveyi*
Pristolepis grootii	*Desmopuntius hexazona*
Trichopodus leerii	*Desmopuntius johorensis*
Trichopodus pectoralis	*Rasbora cephalotaenia*
Trichopodus trichopterus	*Rasbora dorsiocellata*
	Rasbora einthovenii
	Rasbora gracilis
	Rasbora kalochroma
	Rasbora maculata
	Trigonopoma pauciperforatum
	Silurichthys hasseltii
	Sphaerichthys osphromenoides
	Trichopodus leerii
	Trichopodus trichopterus

endangered species (IPT-AWB, 1993; Ng et al., 1994; Lee, 2001; Beamish et al., 2003), where the majority of fish are highly dependent on the rivers in the PSFs (Beamish et al., 2003; Yule, 2010). The degradation of PSFs is expected to affect the fish community structure in such a way that extinction of some already endangered species in the near future is probable. Gibson et al. (2011) reported that converted land-use types vary in their ability to support forest biodiversity, generally having a reduced capacity for biodiversity support than in their original unconverted form. Giam et al. (2012) predicted the number of fish species that would become extinct under different land-use conditions using the Matrix-Calibrated Species-Area Model (MCSAM) (Koh & Ghazoul, 2010) and Mote Carlo simulations to project PSF

basins extinctions. Under the scenario, the 10 most vulnerable species (*Encheloclarias prolatus, B. brownorum, S. goblinus, S. margarition, B. ibanorum, B. burdigala, E. tapeinopterus, Paedocypris progenetica, P. allani* and *H. ornatus*) were recognised and predicted to be extinct by 2050, if the present rate of PSFs conversion continues.

Meanwhile, Beamish et al. (2003) reported 22 species of fish from 43 sites in the NSPSF in 1998 as against 33 species from 27 sites during the preceding year. The PSF was largely forested during the 1997 survey, but the area was cleared and planted with oil palms in 1998. Thirteen species caught in 1997 were not caught in 1998. This supports the prediction by Giam et al. (2012) the extinction of fish species following PSF land conversion. Generally, riparian vegetation acts as a source of energy and matter (Kindler, 1998), and contributes matter to the PSF ecosystem through production of leaf litter (Tabacchi et al., 1998). Modifications in riparian vegetation through logging affect the structure and processes within the peat swamps. It leads to the alteration of the swamp characteristics, reduction of food resources (Tabacchi et al., 1998; Wright & Flecker, 2004) and subsequent loss of biodiversity (Bruenig & Droste, 1995).

Peat swamp forests also serve as an important global carbon storehouse (Parish, 2002; Chimer & Ewel, 2005; Jauhiainen et al., 2005; Rydin & Jeglum, 2006; UNDP, 2006). The PSFs of Malaysia and Indonesia alone store 67 gigatons of carbon in peat, which represents 75% of total tropical peat soil carbon storage (Page et al., 2011). Large scale conversion of this carbon sink, as is happening today, is expected to and will severely impact the earth's climate (Couwenberg et al., 2009; van der Werf et al., 2009; Miettinen et al., 2012) unless drastic measures are put in place to conserve PSFs of the world.

In the discussion of conservation of PSFs fish biodiversity, safe fishing techniques have always been ignored. Researchers, and fishermen alike, employ varying fishing techniques in PSFs and have always been more concerned with increase in catchability than safety and conservation of the fishes. One fishing technique, electro-fishing, that poses a threat to the health of fish has been employed in several surveys in Malaysia PSFs (Martin-Smith & Tan, 1998; Beamish et al., 2003; Shah et al., 2006; Siow et al., 2013). Electro-fishing establishes an electric field in the water (Lamarque, 1990) creating an epileptic response in fish resulting from electric shock to the central nervous system (Reynolds & Kolz, 1993; Sharber & Black, 1999). The reported health effects on fish include internal haemorrhaging and skin discolorations (Dalbey et al., 1996; Kocovsky et al., 1997; Muth & Ruppert, 1997; Thompson et al., 1997; Ainslie et al., 1998; Habera et al., 1999), spinal injuries (Kocovsky et al., 1997), lactacidosis and disturbance of the inter-renal stress response (Mitton & McDonald, 1994), retarded growth (Dalbey et al., 1996; Thompson et al., 1997; Ainslie et al., 1998; Hughes, 1998), and low gamete viability (Muth & Ruppert, 1997; Koupal et al., 1997). Although the

effects of electro-fishing on PSF biodiversity is minor compared to the enormous loss due to PSF drainage, clearance and fire, it is appropriate that only safe fishing techniques such as the use of scoop nets, cast nets, etc. should be employed in a unique habitat such as peat swamps.

CONCLUSION

It is apparent from the ongoing that one of the strongest justifications for conservation of peat swamps is the existing ichthyofauna. Therefore, maintaining fish populations of PSFs is very important as this will require maintaining the natural water tables of the swamps with seasonal flooding. Apart from the necessity to maintain appropriate aquatic habitats for the fish, another important reason is that when peat dries out due to drainage, it is extremely inflammable and thus, becomes highly vulnerable to destruction by fire (Langner et al*.,* 2007; Langner & Siegert, 2009; Page et al*.,* 2009; Posa et al*.,* 2011).

A review of literature on PSF fish and also the IUCN Red List revealed the likelihood of many important fishes becoming extinct in the near future if the present PSFs degradation continues. Moreover, there is also an inevitable risk of increased global warming when the tons of carbon stored in peat lands is released through degradation. Consequently, a concerted effort for conserve regional PSFs is essential, and requires action plans involving all stakeholders (Azmi et al*.,* 2009). The present measures aimed at protecting only some parts of the peat swamp forests in Malaysia are totally inadequate (and in any case, they are largely ignored).

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