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Water Quality Influences on Fish Occurrence in Peat Swamp Forest and Its Converted Areas in North Selangor, Malaysia

(Pengaruh Kualiti Air ke atas Keterdapatan Ikan di Hutan Paya Gambut dan Kawasan Tukaran di Utara Selangor, Malaysia)

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ABSTRACT

Tropical peat swamp forest (PSF) is one of the most endangered ecosystems in the world. However, the impacts of anthropogenic activities in PSF and its conversion area towards fish biodiversity are less understood. This study investigates the influences of water physico-chemical parameters on fish occurrences in peat swamp, paddy field and oil palm plantation in the North Selangor peat swamp forest (NSPSF), Selangor, Malaysia. Fish and water samples were collected from four sites located in the peat swamps, while two sites were located in the paddy field and oil palm plantation areas. Multivariate analyses were used to determine the associations between water qualities and fish occurrences in the three habitats. A total of 1,382 individual fish, belonging to 10 families, 15 genera and 20 species were collected. The family Cyprinidae had the highest representatives, followed by Bagridae and Osphronemidae. The most abundant species was Barbonymus schwanefeldii *(Bleeker 1854), while the least abundant was* Wallago leerii *Bleeker, 1851. The paddy field and oil palm plantation area recorded significantly higher fish diversity and richness relative to peat swamp* ($p<0.05$)*. The water physico-chemical parameters, such as pH, DO,* NH_3*-N,* PO_4*,* SO_4*, and* Cl_2 *showed no significant difference between paddy field and oil palm plantation* ($p>0.05$)*, but was significantly different from the peat swamp* ($p<0.05$)*. However, no water quality parameter was consistently observed to be associated with fish occurrences in all of the three habitats, but water temperature,* NH_3*-N,* Cl_2*,* SO_4*, and EC were at least associated with fish occurrences in two habitats studied. This study confirmed that each habitat possess different water quality parameters associated with fish occurrences. Understanding all these ecological aspects could help future management and conservation of NSPSF.*

Keywords: Fish occurrences; oil palm plantation; paddy field; peat swamp forest; water physico-chemical

ABSTRAK

Hutan paya gambut tropika (PSF) ialah salah satu ekosistem yang semakin terancam di dunia. Walau bagaimanapun, kesan daripada aktiviti antropogenik dalam PSF dan kawasan tukaran terhadap kepelbagaian biologi ikan masih kurang difahami. Penyelidikan ini mengkaji tentang pengaruh parameter fiziko-kimia air terhadap keterdapatan ikan di paya gambut, sawah padi dan ladang kelapa sawit di Hutan Paya Gambut Utara Selangor (NSPSF), Selangor, Malaysia. Sampel ikan dan air telah diambil dari empat tapak yang terletak di paya gambut, dua tapak masing-masing terletak di kawasan sawah padi dan ladang kelapa sawit. Analisis multivariat telah digunakan untuk menentukan kaitan antara kualiti air dan keterdapatan ikan di tiga habitat. Sebanyak 1,382 individu ikan, milik 10 famili, 15 genus dan 20 spesies telah dikumpul. Famili Cyprinidae mempunyai wakil yang tertinggi, diikuti oleh Bagridae dan Osphronemidae. Spesies paling banyak adalah Barbonymus schwanefeldii *(Bleeker 1854), manakala spesies paling sedikit adalah* Wallago leerii *Bleeker, 1851. Kawasan sawah padi dan ladang kelapa sawit mencatatkan kepelbagaian ikan jauh lebih tinggi dan kaya berbanding dengan paya gambut* ($p<0.05$)*. Parameter fisiko-kimia air seperti pH, DO,* NH_3*-N,* PO_4 *dan* SO_4 *dan* Cl_2 *tidak menunjukkan perbezaan yang signifikan antara sawah padi dan ladang kelapa sawit* ($p>0.05$)*, tetapi berbeza secara ketara daripada paya gambut* ($p<0.05$)*. Walau bagaimanapun, tiada parameter kualiti air diperhatikan secara konsisten boleh dikaitkan dengan keterdapatan ikan dalam kesemua tiga habitat, tetapi suhu air,* NH_3*-N,* Cl_2*,* SO_4 *dan EC sekurang-kurangnya dikaitkan dengan keterdapatan ikan dalam dua habitat yang dikaji. Kajian ini mengesahkan bahawa setiap habitat mempunyai parameter kualiti air yang berbeza yang berkait rapat dengan keterdapatan ikan. Memahami kesemua aspek ekologi akan membantu masa depan pengurusan dan pemuliharaan NSPSF.*

Kata kunci: Fiziko-kimia air; hutan paya gambut; keterdapatan ikan; ladang kelapa sawit; sawah padi

INTRODUCTION

Tropical peat swamp forests (PSF) is one of the most endangered ecosystems in the world. In the south east Asia region, these forests are destroyed at an unprecedented rate (Yule 2010). One of the most threatened PSF is the North Selangor peat swamp forest (NSPSF), Malaysia, which has been reportedly halved from 0.67 million ha in 1981 to 0.3 million ha in the 1990s, due to peatland clearing and draining for agriculture and industrial purpose (UNDP 2006). The recent desire for agricultural development and expansion resulted in the destruction of a large part of the forest and its subsequent conversion to paddy fields and oil palm plantations (Giam et al. 2012). Consequently, the agricultural parts of the NSPSF is now characterized by intense anthropogenic activities (Posa et al. 2011).

North Selangor peat swamp forest is home to diverse fish species, some of which are stenotopic to the peat swamp of the forest (Beamish et al. 2003). Most studies on fish diversity in NSPSF focused on documenting only the fish species resident in peat swamps (Ahmad & Samat 2015; Ahmad et al. 2013; Beamish et al. 2003; Davies & Abdullah 1989; IPT-AWB 1993; Ismail et al. 2013; Ng et al. 1994; Siow et al. 2013). Current studies reported a total of 198 peat swamp fish species from 32 families from Malaysia. From that, a total of 114 species from 23 families, representing ~40% of the known fish fauna in Peninsular Malaysia was recorded from NSPSF alone (Sule et al. 2016). Even with the conversion of a substantial part of NSPSF into agriculture plantation, many areas remain flooded with water for most part of the year. However, studies on the NSPSF's fish diversity largely continued to ignore the diversity of fish species in the nearby agricultural habitat, especially in paddy fields and oil palm plantations. As a result, fragmentary information exists on the diversity of fish in converted paddy fields and oil palm plantations.

Water quality is a broad term used to referring to the physical, chemical, biological, and radiological characteristics of water. It is often employed as a measure of water condition relative to the life requirements of biotic species and human need. Several studies detailing the influence of water quality on fish aggregation has been employed, mostly in the form of a combined physico-chemical parameters (Beamish et al. 2006, 2003; Dubey et al. 2012; Fischer & Paukert 2008) and rarely biological parameters (Ismail et al. 2016). Generally, different parameters of water quality had been shown to predictably influence fish communities in a wide range of aquatic habitats (Beamish et al. 2006, 2003; Dubey et al. 2012; Fischer & Paukert 2008; Ikhwanuddin et al. 2016; Rashid et al. 2018).

Although several studies reported a decline in fish diversity following habitat loss due to PSF degradation, only a few studies focused on fish aggregation relative to the water quality parameters in NSPSF (Beamish et al. 2003). Moreover, studies detailing the influence of water quality on fish occurrence in the highly human impacted agricultural areas of the NSPSF are generally absent. This study seeks to determine the influence of water physico-chemical parameters on fish occurrence in peat swamp, paddy field and oil palm plantation of NSPSF, Selangor, Malaysia. It is expected that the results from this study could help to understand the ecology of fishes in PSF and its converted area for future management and conservation.

Materials and Methods

STUDY AREA

The study was conducted in the NSPSF, a flat coastal plain located in a humid tropical zone of the northern region of Selangor, Malaysia. It is ~81,304 ha, with four Forest Reserve within it, namely Raja Musa Forest Reserve; Sungai Karang Forest Reserves; part of Bukit Belata Extension Forest Reserve; and Sungai Dusun Forest Reserve/Wildlife Reserve. Following the conversion of substantial parts of the peat swamp forest into agriculture, it is now divided into a reserved PSF and agricultural areas. A stretch of paddy fields, which is one of the primary rice granary areas in Malaysia, covering an area of 18,980 ha, is now evident on map and extends almost the entire length of the costal part of NSPSF (GEC 2014) (Figure 1). Besides paddy, a large part of the PSF is now dominated by oil palm plantation (Irvine et al. 2013).

The mean annual rainfall ranges from 1,359 - 2,480 mm, while the mean temperature and mean relative humidity are 27°C and 79.3%, respectively. There are two distinct seasons in the area; wet/rainy seasons (March-April and October-November) and relatively dry seasons (January-February and May-September) (GEC 2014).

SAMPLING SITES

Eight sampling sites were surveyed in this study. Four of the sites were located in the peat swamps, while two were located in the paddy field and oil palm plantation areas. The sites are localized within the Kampung Sungai Sireh, Tanjong Karang, Selangor, such that all the peat swamp sites on one side were separated from the paddy field and oil palm plantation sites by Sungai Tengi, Tanjong Karang, Selangor, along its entire length (Figure 1).

Sungai Tengi is used to irrigate the paddy fields and oil palm plantations via numerous irrigation canals. During wet season of high rainfall, water from the river overflow into the peat swamps on one side and the paddy and oil palm areas on the other and *vice versa*. Hence, water from the peat swamps, agricultural areas and Sungai Tengi co-mingle at intervals (Irvine et al. 2013; Yule & Gomez 2008). By implication, therefore, there exist the possibility of fish migration through the water networks, from the peat swamps to Sungai Tengi, to paddy or oil palm plantation and *vice versa*. Water quality and fish collection were conducted in June 2015 (dry month), October 2015 (relatively high rainfall month) and January 2016 (moderately dry month).

PEAT SWAMP SITES

Peat swamp site 1 was located at 3° 34' 40.5444'' N, 101° 7' 0.4152'' E; site 2 at 3° 33' 7.1712'' N, 101° 8' 36.15'' E; site 3 at 3° 31' 9.4188'' N, 101° 10' 43.7736'' E and site 4 at 3° 29' 45.7692'' N, 101° 12' 37.8864'' E. Peat swamp site 1 had undergone significant logging, and was dominated by shrubs, with only very few trees present. During the third

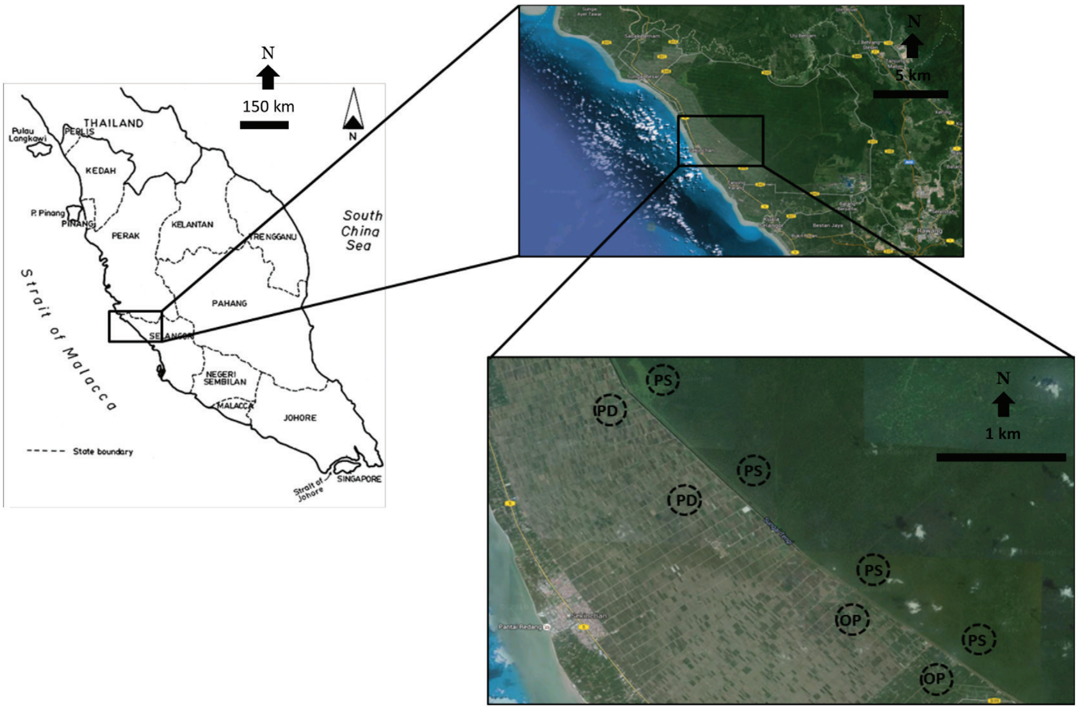

FIGURE 1. Map of Peninsular Malaysia showing study area and sites of sample collection in peat swamp, paddy field and oil palm plantation in north Selangor peat swamp forest

visit to the site, we noticed it was further degraded, with the majority cleared and burnt. A major dumpsite is close to the site. Peat swamps sites 2 and 3 had also undergone some logging, but had more vegetation cover than site 1 and lesser than site 4. Peat swamp site 4 appeared to be pristine, preserved in its natural form and untouched. The site was almost completely covered with vegetation, with many mature dipterocarp and other trees. It was relatively hidden and difficult to access.

PADDY FIELD SITES

The paddy field sites 1 and 2 were located at 3° 34' 15.4164'' N, 101° 6' 43.2864'' E and 3° 32' 40.8012'' N, 101° 8' 23.892'' E, respectively. The paddy sites were typically artificial freshwater swamps, dominated by the paddy with shrubs at the bank. The entire areas within the sites were completely exposed to direct sunlight without any trees. These sites were converted from the PSF, as evident in the peat characteristics retained in the soil and water. The sites were characterized by the presence of trenches and screens firmly/loosely placed at interval. Some of the screens were damaged with openings big enough for a large fish to pass. The paddies within each site were partitioned by dikes made of dried peat, sometimes with hardened clay soil. There were networks of large irrigation canals, leading from the paddy sites to Sungai Tengi. Within the proximity of each site were human dwellings and other agricultural infrastructures. Intense application of insecticides/pesticides was observed during the visits.

OIL PALM PLANTATION SITES

Oil palm sites 1 and 2 were located at 3° 30' 41.7384'' N, 101° 10' 32.2068'' E and 3° 29' 19.8816'' N, 101° 12' 31.5864'' E, respectively. The sites were dominated by oil palm trees. Few dipterocarp and other trees were present at each site. The sites were flooded with water during each visit. There was irrigation canals leading to Sungai Tengi present at each site. There were oil palm fruits and kernels, which probably serve as food to fish resident in the sites. Oil palm site 1 was very close to human settlement. The water was visibly polluted with domestic effluents and plastics. The irrigation canal in the oil palm site 1 received direct discharge of waste water. Oil palm site 2 is relatively further away from human settlement. Although no direct effluent discharge into the canals was observed, the water was visibly polluted. The oil palm site 2 was used as a major litter site.

FISH COLLECTION

The fish samples were collected using a combination of cast net and scoop nets, each with a mesh size of 0.5 cm. One person utilized the cast net while two persons used the scoop nets in areas of the water habitats with submerged branches or too shallow for the use of the cast net. Each sampling site was at least 200 m long and a minimum of 2 h were spent at each site. Samplings were conducted at consistent sites throughout the sampling season. Individual fish species caught were enumerated at each sampling site and two representatives of each suspected species were transported back to the laboratory for identification. At each site, one representatives of each species were fixed in 10% formalin and later transferred to 70% ethanol solution, while the second representatives were transferred into labeled aquaria supplied with oxygen for transportation to the laboratory. This was to avoid taxonomic confusion resulting from color changes after a species is fixed.

Identifications of fish species were made based on previous literatures (Ahmad & Samat 2015; Ahmad et al. 2013; Ambak et al. 2010; Beamish et al. 2003; Davies & Abdullah 1989; IPT-AWB 1993; Ismail et al. 2013; Ng et al. 1994; Siow et al. 2013). References were made to Froose and Pauly (2016) and Kottelat (2013) for the latest taxonomic revision. The IUCN status of each fish species collected was determined using conservation assessment of the IUCN Red List of Threatened Species (IUCN 2015).

WATER PHYSICOCHEMICAL ANALYSES

Water temperature, pH, dissolved oxygen (DO), total dissolved substance (TDS), electrical conductivity (EC) and salinity were measured at each sampling site using a YSI 556 MPS probe (YSI Incorporation, NY, USA). A total of 500 mL of water sample was collected in sterilized polyethylene sampling bottle in replicates from 15 cm below the water surface at each sampling station and transferred into an ice box. The samples were immediately transported to the laboratory for further analysis. The chlorine (Cl_2), nitrite (NO_3-N), phosphate (PO_4), sulphate (SO_4) and ammonia-nitrogen (NH_3-N) concentration were measured using a DR900 Multiparameter Handheld Calorimeter (Hach Company, Loveland, Colorado, USA). Analyses and sample collection were done between 8.00 AM and 12.00 AM during the sampling period.

STATISTICAL ANALYSES

All analyses relating to simple percentages of fish collected were performed in Microsoft Excel (Office 365, Version 2016, Microsoft Corp., Berkshire, UK). The fish species Shannon-Weaver diversity index (*H'*) (Shannon & Weaver 1963), Pielou's evenness index (*e*) (Pielou 1969) and Margalef's richness index ($I_{Margalef}$) (Margalef 1958) were also calculated and subjected to one-way analysis of variance (ANOVA) and Tukey's pairwise test (IBM SPSS, Version 22.0, IBM Corp., Chicago, IL, USA).

Water physicochemical parameters were analyzed using IBM SPSS. The Shapiro-Wilk test confirmed that the data conformed to normality, was subjected to ANOVA and Tukey's pairwise comparisons (p=0.05) to test for significant difference between the water physicochemical data of the three habitats.

Then, the 11 water physicochemical parameters measured were used to identify the relationship between water physicochemical parameters and fish occurrence in each habitat studied. Data reduction was performed with Principal Component Analysis (PCA) using IBM SPSS to reduce variable numbers in the dataset by combining highly correlated variables into factors, while retaining variability in the data. Generally, dataset comprised of numerous variables are likely to be redundant if two or more are highly correlated (Mandal et al. 2012).

The water physicochemical variables that showed variation within each habitat were used to determine the effects of its physicochemical parameters on the fish occurrence using Canonical Correspondence Analysis (CCA). The CCA was performed using XLSTAT add-in (Version 2014.5.3, Addinsoft, New York, NY, USA) for Microsoft Excel. The significance of each variable was tested using CCA XLSTAT-ADA with 5000 permutations at a significance level of 5%. The results are presented using canonical biplots and other descriptive statistics.

RESULTS

FISH SPECIES COLLECTED

A total of 20 fish species from 10 families were collected. A total of 15 species belonging to nine families, 19 species belonging to nine families and 20 species belonging to 10 families were collected from the peat swamp, paddy field and oil palm plantation, respectively. Overall, 1,382 individual fishes were collected, comprising of 285 from peat swamps, 388 from paddy fields and 709 from oil palm areas. The most abundant species was *Barbonymus schwanefeldii* (Bleeker 1854), with 169 individuals, while the least abundant species was *Wallago leerii* Bleeker 1851, with only one collected individual throughout the study. Most of the fishes were categorized under least concerned (13 species; 65%) by IUCN Red List of Threatened Species, while no endangered fish species was collected (Table 1).

FISH COMMUNITY STRUCTURE

There was a significant difference between fish diversity of the three habitats (F = 22.09, df = 2, 9, p<0.05). Significantly higher fish diversity was observed in paddy fields (*H'* = 2.6167) and oil palm (*H'* = 2.6153) compared to peat swamp area (*H'* = 2.4243) (p<0.05). However, there was no significant difference in fish diversity between paddy field and oil palm areas (p>0.05). The results of ANOVA test showed there was no significant difference in fish evenness for the three habitats (F = 4.50, df = 2, 9, p>0.05). However, there was a significant difference in fish richness between all of the sampling habitats (F = 142.59, df = 2,9, p<0.05). The highest fish richness was recorded in paddy field ($I_{Margalef}$ = 3.0196), followed by oil palm plantation ($I_{Margalef}$ = 2.8946) and peat swamp areas ($I_{Margalef}$ = 2.4768) (Table 2).

WATER PHYSICO-CHEMICAL PARAMETERS

In this study, water temperature showed no significant difference between the three habitats studied (F = 0.461, df = 2, 21, p>0.05) (Table 3). However, significant differences were observed for pH (F = 47.686, df = 2, 21, p<0.05) and DO (F = 214.513, df = 2, 21, p<0.05) between the three habitats studied. Peat swamp had the lowest pH and DO relative to paddy field and oil palm plantation (p < 0.05).

TABLE 1. List of family, fish species, IUCN status, number and percentages of fish collected from peat swamp, paddy field and oil palm plantation in north Selangor peat swamp forest

Family	Species	Abbrev.	IUCN	Peat swamp (n = 285)		Paddy field (n = 388)		Oil palm (n = 709)		Cumulative (N = 1382)	
				No.	%	No.	%	No.	%	No.	%
Anabantidae	*Anabas testudineus* (Bloch, 1792)	A.tes	DD	13	4.56	11	2.84	10	1.41	34	2.46
Bagridae	*Hemibagrus nemurus* (Valenciennes, 1840)	H.nem	LC	3	1.05	3	0.77	6	0.85	12	0.87
Bagridae	*Hemibagrus planiceps* (Valenciennes, 1840)	H.pla	NE	0	0.00	3	0.77	9	1.27	12	0.87
Bagridae	*Mystus nigriceps* (Valenciennes, 1840)	M.nig	NE	5	1.75	2	0.52	4	0.56	11	0.80
Channidae	*Channa melasoma* (Bleeker, 1851)	C.mel	LC	4	1.40	2	0.52	12	1.69	18	1.30
Clariidae	*Clarias leiacanthus* Bleeker, 1857	C.lei	NE	4	1.40	5	1.29	9	1.27	18	1.30
Cyprinidae	*Barbonymus gonionotus* (Bleeker, 1850)	B.gon	LC	0	0.00	6	1.55	26	3.67	32	2.32
Cyprinidae	*Barbonymus schwanefeldii* (Bleeker, 1854)	B.sch	LC	29	10.18	43	11.08	97	13.68	169	12.23
Cyprinidae	*Cyclocheilichthys apogon* (Valenciennes, 1842)	C.apo	LC	11	3.86	28	7.22	63	8.89	102	7.38
Cyprinidae	*Cyclocheilichthys heteronema* (Bleeker, 1853)	C.het	LC	0	0.00	37	9.54	115	16.22	152	11.00
Cyprinidae	*Osteochilus vittatus* (Valenciennes, 1842)	O.vit	LC	17	5.96	35	9.02	79	11.14	131	9.48
Cyprinidae	*Parachela oxygastroides* (Bleeker, 1852)	P.oxy	LC	16	5.61	13	3.35	48	6.77	77	5.57
Cyprinidae	*Rasbora dusonensis* (Bleeker, 1850)	R.dus	NE	7	2.46	25	6.44	65	9.17	97	7.02
Cyprinidae	*Rasbora tornieri* Ahl, 1922	R.tor	LC	0	0.00	3	0.77	43	6.06	46	3.33
Helostomatidae	*Helostoma temminckii* Cuvier, 1829	H.tem	LC	43	15.09	37	9.54	23	3.24	103	7.45
Notopteridae	*Notopterus notopterus* (Pallas 1769)	N.not	LC	19	6.67	21	5.41	29	4.09	69	4.99
Osphronemidae	*Trichopodus trichopterus* (Pallas, 1770)	T.tri	LC	47	16.49	33	8.51	27	3.81	107	7.74
Osphronemidae	*Trichopodus pectoralis* Regan, 1910	T.pec	LC	31	10.88	38	9.79	26	3.67	95	6.87
Pristolepididae	*Pristolepis grootii* (Bleeker, 1852)	P.gro	NE	36	12.63	43	11.08	17	2.40	96	6.95
Siluridae	*Wallago leerii* Bleeker, 1851	W.lee	NE	0	0.00	0	0.00	1	0.14	1	0.07

NE = Not Evaluated; LC = Least Concern; DD = Data Deficient

TABLE 2. Fish community structure in peat swamp, paddy field and oil palm expressed as diversity, evenness and richness index

Habitat	Community structure index		
	Shannon's *H*	Pielou's *e*	$I_{Margalef}$
Peat swamp	2.4243[a]	0.8952[a]	2.4768[a]
Paddy field	2.6167[b]	0.8887[a]	3.0196[c]
Oil palm	2.6153[b]	0.8730[a]	2.8946[b]

Shannon's *H* = Shannon-Weiner diversity index; Pielou's *e* = Pielou's evenness index; $I_{Margalef}$ = Margalef's richness index. Indices within the same column followed by different superscript letters are significantly different (Tukey's pairwise test, p=0.05)

There were no significant differences between paddy field and oil palm plantation in terms of pH and DO (p>0.05).

Significant differences were also observed for EC ($F = 10.165$, df = 2, 21, p<0.05) and TDS ($F = 7.557$, df = 2, 21, p<0.05) between the three habitats studied. Significantly higher means of EC and TDS were recorded in the peat swamp compared to paddy field (p<0.05), but were not significant different from oil palm plantation (p>0.05).

Overall, even though the salinity was considered to be low, a significant difference was observed between the three habitats ($F = 4.631$, df = 2, 21, p<0.05). In this study, the highest salinity was recorded in the peat swamp, followed by paddy field which was significantly higher than oil palm plantation (p<0.05).

There were significant differences between the three habitats in terms of NH_3-N ($F = 8.697$, df = 2, 21, p<0.05) and NO_3-N ($F = 0.801$, df = 2, 21, p<0.05) contents. Oil palm plantation recorded the highest NH_3-N concentration, followed by paddy field (p>0.05) which were significantly higher than peat swamp (p<0.05). The lowest NO_3-N was recorded in the peat swamp followed by oil palm (p>0.05) which were significantly lower compared to paddy field (p<0.05).

In this study, peat swamp recorded significantly higher PO_4, SO_4 and Cl_2 relative to paddy field and oil palm areas (PO_4: $F = 280.876$, df = 2, 21, p<0.05; SO_4: $F = 8.09$, df = 2, 21, p<0.05; Cl_2: $F = 5.179$, df = 2, 21, p<0.05).

PRINCIPAL COMPONENT ANALYSIS OF WATER PHYSICO-CHEMICAL PARAMETERS

Principal component extraction and component loadings from principal component analysis of water physico-chemical parameters from peat swamp, paddy field, and oil palm plantation, as per in Table 4. For each habitat, PCA produced two axes that cumulatively explained the 88.25%, 97.70%, and 83.60% variation of waters' physicochemical parameters in the habitats, respectively. The extraction was based on eigenvalues of 1 or greater, which is considered significant (Zhang et al. 2011). Out of the 11 water physico-chemical parameters evaluated, only four parameters were retained in each habitat. The parameters of water temperature, EC, NH_3-N, and Cl_2 were retained in peat swamp; NH_3-N, PO_4, SO_4, and Cl_2 were retained in paddy field; while temperature, DO, EC and SO_4 were retained in the oil palm.

In the case of peat swamp, the first axis had strong loadings of temperature, NH_3-N, and Cl_2, while the second axis reported a high loading of EC. The measured NH_3-N, PO_4, and Cl_2 had high loadings on the first axis, while SO_4 had high loading on the second axis in paddy field. Meanwhile, for the oil palm plantation, the first axis had strong loadings of DO and EC, while the second axis had high loadings of temperature and SO_4. Generally, factor loadings are classified as strong (> 0.75), moderate (0.75–0.50), or weak (0.50–0.30) (Liu et al. 2003).

TABLE 3. Water quality parameters recorded in peat swamp, paddy field and oil palm of north Selangor peat swamp forest

	Peat swamp		Paddy field		Oil palm	
	Mean ± SD	Range	Mean ± SD	Range	Mean ± SD	Range
Temp (°C)	31.62 ± 2.70[a]	27.80 – 35.70	30.65 ± 2.23[a]	28.30 – 33.80	30.71±1.80[a]	28.10 – 33.10
pH (1 – 14)	3.69 ± 0.25[a]	3.28 – 4.10	4.96 ± 0.46[b]	4.26 – 5.57	5.61 ± 0.62[b]	4.62 – 6.17
DO (mg L^{-1})	0.59 ± 0.17[a]	0.36 – 0.86	3.16 ± 0.56[b]	2.49 – 3.89	3.58 ± 0.30[b]	3.17 – 3.97
EC (µS cm^{-1})	204.85 ± 29.70[a]	155.70 – 271.00	92.94 ± 41.57[b]	61.00 – 156.03	108.12 ± 99.82[ab]	32.00 – 241.90
TDS (g L^{-1})	0.13 ± 0.02[a]	0.10 – 0.17	0.06 ± 0.03[b]	0.04 – 0.10	0.07 ± 0.07[ab]	0.02 – 0.18
Salinity (ppt)	0.05 ± 0.04[a]	0.01 – 0.12	0.02 ± 0.01[a]	0.01 – 0.03	0.01 ± 0.00[b]	0.01 – 0.12
NH_3-N (mg L^{-1})	0.35 ± 0.08[a]	0.23 – 0.45	0.45 ± 0.03[b]	0.41 – 0.50	0.46 ± 0.04[b]	0.39 – 0.50
NO_3-N (mg L^{-1})	0.002 ± 0.003[a]	0.000 – 0.008	0.005 ± 0.004[b]	0.000 – 0.009	0.003 ± 0.005[ab]	0.000 – 0.012
PO_4 (mg L^{-1})	1.94 ± 0.20[a]	1.56 – 2.30	0.37 ± 0.12[b]	0.22 – 0.56	0.38 ± 0.10[b]	0.28 – 0.56
SO_4 (mg L^{-1})	28.92 ± 20.40[a]	11.00 – 68.00	3.33 ± 1.21[b]	2.00 – 5.00	5.83 ± 3.19[b]	2.00 – 11.00
Cl_2 (mg L^{-1})	0.92 ± 0.36[a]	0.46 – 1.60	0.63 ± 0.72[b]	0.10 – 2.00	0.21 ± 0.10[b]	0.05 – 0.31

Comparison is between mean ± SD along the same row. [a,b] Different superscript letters are significantly different between the same rows (Tukey's pairwise test, p = 0.05)

TABLE 4. Principal component loadings from principal component analysis of water quality parameters from peat swamp, paddy field and oil palm of north Selangor peat swamp forest

	Peat swamp		Paddy field		Oil palm	
	C1	C2	C1	C2	C1	C2
Eigenvalue	2.501	1.029	2.763	1.145	1.754	1.590
Percentage variance explained	62.535	25.714	69.086	28.613	43.858	39.738
Cumulative variance explained	62.535	88.249	69.086	97.699	43.858	83.597
Temperature (°C)	**0.875**	0.195			-0.097	**0.840**
DO (mg L^{-1})					**0.873**	-0.324
EC (μS cm^{-1})	0.048	**0.994**			**0.911**	0.167
NH_3-N (mg L^{-1})	**0.949**	0.016	**0.971**	0.168		
PO_4 (mg L^{-1})			**0.977**	-0.110		
SO_4 (mg L^{-1})			-0.060	**0.996**	0.100	**0.911**
Cl_2 (mg L^{-1})	**0.913**	-0.052	**0.929**	-0.336		

Strong loadings > 0.70 in **bold**

CANONICAL CORRESPONDENCE ANALYSIS OF WATER PHYSICO-CHEMICAL PARAMETERS

All four variables of water physico-chemical parameters of each habitat from the PCA were retained by CCA. These variables were significant contributors to the variation in CCA's ordination. Four ordination axes were generated for the CCA in each habitat. The cumulative percentages for the first and second ordination axes were 44.26% and 71.52%, 39.68% and 76.58% and 51.67% and 79.53% for peat swamp, paddy field and oil palm plantation, respectively (Table 5). Only the first two axes are reported here, since these axes contributed the most to the ordination.

For peat swamp, with respect to the first and second ordination axes only, the former was positively correlated with temperature and EC and negatively correlated with NH_3-N and Cl_2, while the latter is positively correlated with temperature and NH_3-N, but negatively correlated with EC and Cl_2. The first axis for paddy field was negatively correlated with NH_3-N and PO_4, but was positively correlated with SO_4 and Cl_2, while the second axis was positively correlated with NH_3-N and PO_4 and negatively correlated with SO_4 and Cl_2. In the case of the oil palm plantation, both axes were positively correlated with temperature, DO and EC. However, for SO_4, the first axis was negatively correlated with SO_4 while the second axis was positively correlated with SO_4.

EFFECTS OF THE CONVERSION OF PEAT SWAMP ON WATER PHYSICO-CHEMICAL AND FISH OCCURRENCE

Figure 2 shows a CCA ordination diagram, depicting the relationship between water physico-chemical parameters and occurrence of 15 fish species in peat swamp. The longest CCA vector was observed for EC, followed by temperature, Cl_2 and NH_3-N. Based on the ordination diagram, fish species, such as *Channa melasoma*, *Rasbora dusonensis*, *Helostoma temminckii*, *Anabas testudineus*, *Osteochilus vittatus*, *Cyclocheilicthys apogon* and *Pristolepis grootii* were positively correlated with EC,

TABLE 5. Canonical correspondence analysis summary statistics of physicochemical parameters of water

	Peat swamp				Paddy field				Oil palm			
	F1	F2	F3	F4	F1	F2	F3	F4	F1	F2	F3	F4
Eigenvalue	0.062	0.038	0.027	0.012	0.107	0.100	0.047	0.016	0.051	0.027	0.015	0.005
Constrained inertia (%)	44.261	27.260	19.578	8.901	39.677	36.904	17.477	5.942	51.673	27.856	14.962	5.509
Cumulative %	44.261	71.521	91.099	100.000	39.677	76.581	94.058	100.000	51.673	79.529	94.491	100.000
Regression coefficients:												
Temperature (°C)	1.209	1.107	0.771	0.110					0.039	0.039	1.088	0.313
DO (mg L^{-1})									0.723	0.266	1.228	-0.726
EC (μS cm^{-1})	0.421	-0.709	-0.169	-0.635					0.427	0.417	-0.647	0.948
NH_3-N (mg L^{-1})	-0.115	0.440	-2.485	-0.184	-1.828	0.241	0.066	3.335				
PO_4 (mg L^{-1})					-2.561	1.181	0.549	-2.799				
SO_4 (mg L^{-1})					1.140	-1.566	-0.209	-1.052	-0.008	0.379	-0.404	-1.004
Cl_2 (mg L^{-1})	-0.528	-1.563	1.521	0.997	4.795	-2.309	0.292	-0.837				

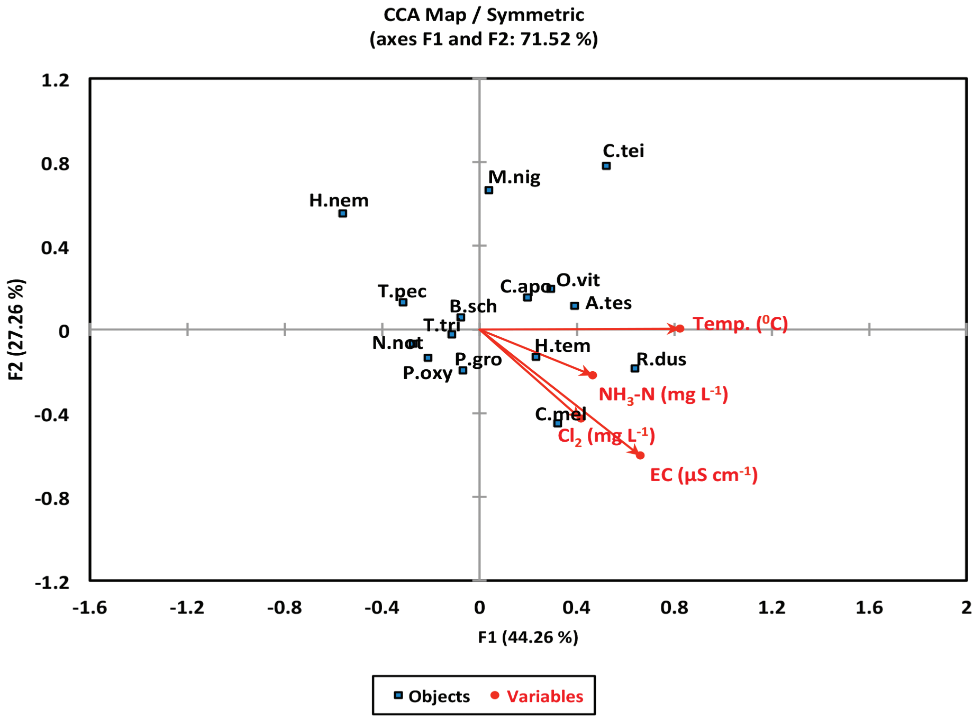

FIGURE 2. Canonical correspondence analysis ordination diagram showing the effect of physicochemical water parameters on fish occurrence in peat swamp

NH_3-N and Cl_2. *Channa melasoma*, *R. dusonensis*, *H. temminckii*, *A. testudineus*, *O. vittatus*, *C. apogon*, *Mystus nigriceps* and *Clarias leiacanthus* were influenced by water temperature. Meanwhile, species such as *Trichopodus trichopterus*, *B. schwanefeldii*, *Parachela oxygastroides*, *Notopterus notopterus*, *T. pectoralis* and *Hemibagrus nemurus* were negatively correlated with all of the water's physicochemical variables.

The effects of water physicochemical parameters on the occurrence of 19 fish species recorded in paddy field are presented in Figure 3. Based on the length of the CCA vector, SO_4 was the most important water physicochemical variable determining fish occurrence, followed by NH_3-N and PO_4, while Cl_2 was the least important. Briefly, species such as *C. melasoma*, *H. nemurus*, *H. temminckii P. grootii* and *B. gonionatus* showed a marked increase in occurrence with increased SO_4, NH_3-N and PO_4, denoting a positive correlation. On the other hand, the occurrence of *M. nigriceps*, *H. planiceps*, *R. dusonensis*, *R. tornieri*, *O. vittatus*, *T. trichopterus*, *T. pectoralis* and *N. notopterus* showed negative correlation with the variables. Meanwhile, *A. testudineus*, *B. schwanefeldii*, *C. heteronema* and *P. oxygastroides* exhibited weak associations with the water's physico-chemical variables.

Figure 4 shows the ordination diagram depicting the relationship between the water physico-chemical parameters and fish occurrence in oil palm plantations. All of the water physico-chemical parameters are important based on the vector length of the ordination diagram. Based on the CCA vector, species such as *C. melasoma* and *M. nigriceps* showed a negative correlation with the water physico-chemical variables. Species such as *W. leeri*, *B. gonionotus*, *C. apogon* and *A. testudineus* showed positive correlation with EC and DO. Similarly, the occurrence of *H. planiceps*, *R. tornieri*, *T. pectoralis*, *T. trichopterus*, *N. notopterus*, *H. nemurus* and *C. leiacanthus* showed positive correlation with SO_4 and temperature. However, species such as *P. oxygastroides*, *H. temminckii* and *C. heteronema* displayed weak correlations with all of the water physico-chemical parameters.

DISCUSSION

In this study, a total of 1,382 individual fish, belonging to 10 families, 15 genera and 20 species were collected. Approximately, about 114 species of fish, representing ~ 40% of the known fish fauna of Peninsular Malaysia, have been documented in NSPSF (Sule et al. 2016). One of the earliest survey in the NSPSF by Davies and Abdullah (1989) recorded a total of 41 species from 11 families. This number increased to 76 species from 23 families, following an intensive survey by IPT-AWB (1993), aimed at updating the known fish diversity of the NSPSF. A year after this survey, however, Ng et al. (1994) documented 47 species from 17 families, which is a reduction of species count by 29. Similarly, Beamish et al. (2003), during a two year survey, reported 31 species in 1997, but the number was reduced to 22 species in 1998, following peat forest clearing. Similarly, Ahmad and Samat (2015) recorded only 22 species from 10 families. From our study, only 20 species, belonging to 10 families were recorded. Although the seasons, fishing gears and techniques employed in

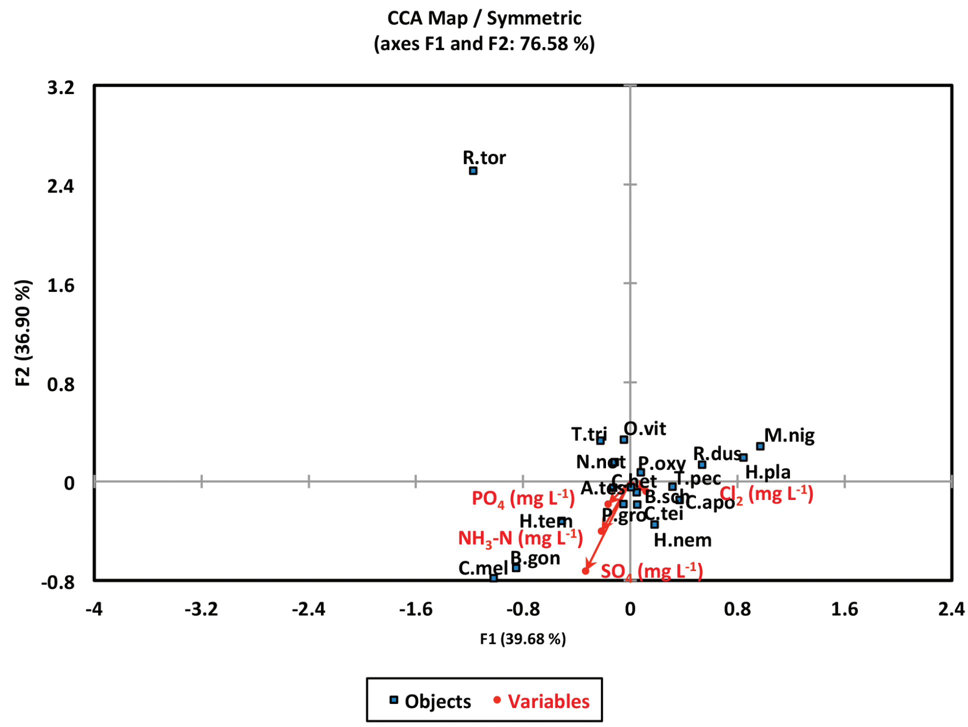

FIGURE 3. Canonical correspondence analysis ordination diagram showing the effect of physicochemical water parameters on fish occurrence in paddy field

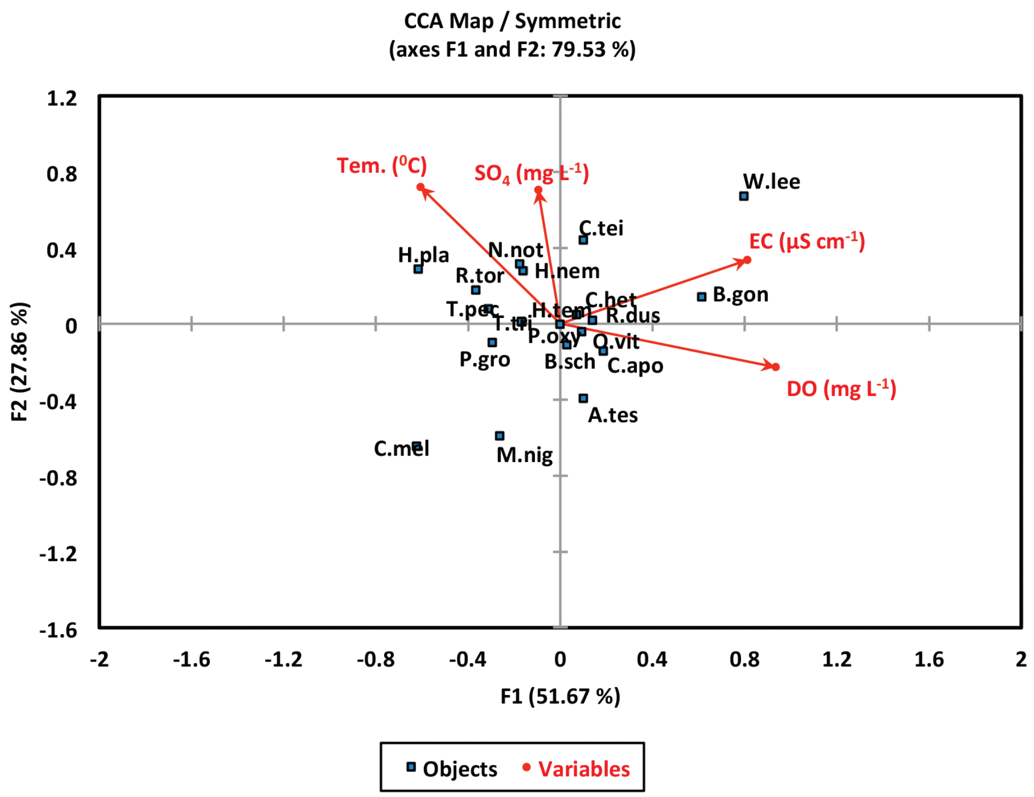

FIGURE 4. Canonical correspondence analysis ordination diagram showing the effect of physicochemical water parameters on fish occurrence in oil palm plantation

surveys have the tendency to influence the results of fish diversity, the trend in the reduction of species encountered in NSPSF over the years is attributed to the destruction of PSF and its subsequent conversion to agriculture and industries (UNDP 2006).

From our study, peat swamp showed lower fish diversity and richness relative to paddy fields and oil palm areas. NSPSF has been severely degraded over the past decade, with a record reduction from 0.67 million ha in 1981 to 0.34 million ha in the 1990s (UNDP 2006). There has been a marked increase in the agricultural areas, such as paddy field and oil palm plantation, as more PSF has been converted to agriculture. Furthermore, constant irrigation of these agricultural areas with water from the peat swamps and Sungai Tengi via numerous irrigation canals facilitated the migration and distribution of fish species into agricultural areas. These areas, although undisturbed, has become a safer breeding ground for some fish species in NSPSF hence the higher fish diversity and richness observed in the agricultural areas compared to the peat swamp of NSPSF. Moreover, less fish species could survive in extreme habitat with low water DO and pH such as in PSF (Ng et al. 1994).

All of the 15 fish species collected from peat swamp have previously been documented in the NSPSF (Ahmad et al. 2013; Beamish et al. 2003; Davies & Abdullah 1989; IPT-AWB 1993; Ismail et al. 2013; Ng et al. 1994; Siow et al. 2013). Previous surveys in the NSPSF largely ignored the agricultural areas of paddy field and oil palm plantation. The focus of their survey was on documenting the fish diversity in the peat swamps before they become completely destroyed and converted for agriculture, industrialization and settlement urbanization (Beamish et al. 2003; Ng et al. 1994). As a result of this, fragmentary information exists on the fish diversity and occurrence in the paddy field and oil palm plantation of the NSPSF. Interestingly, other than *A. testudineus*, common fish widely cultured in paddy fields such *C. striata* and *C. batrachus* were not collected in this study. The physical characteristics of the paddy field sites, such as the presence of trenches and dikes, suggest that it may have been constructed for paddy-cum-fish culture. This could also indicate that the collected fish species have migrated from the peat swamp and Sungai Tengi, and not necessarily stocked.

This study showed that water temperature, EC, DO, NO_3-N, and Cl_2 influence fish occurrence in at least one of the habitat studied, even though the occurrence is influenced by different water physico-chemical parameters in each habitat. Water conductivity doubles as the most important parameter in peat swamp and oil palm and was inversely correlated with the occurrence of species, such as *T. pectoralis*, *T. trichopterus*, *N. notopterus*, *B. schwanefeldii* and *R. tornieri*. Generally, EC has been reported to influence fish occurrence in fresh water habitats (Beamish et al. 2003; Dubey et al. 2012; Fischer & Paukert 2008). This may not be unconnected with the tendency of high level of EC to inhibit NH_3-N excretion in the fishes (Wilkie & Wood 1991). Water temperature also displayed significant importance in influencing fish occurrence in peat swamp, as well as in oil palm areas and has been reported as a very important parameter influencing fish occurrence in various habitats and ecosystems (Beamish et al. 2006; Dubey et al. 2012) due to its ability to modulate physiological activities and inducing stress in fish (von Herbing 2002). The relatively high temperature recorded in this study (≤31.62°C) can be attributed to extensive land clearing, leaving the water bodies directly exposed to sunlight.

SO_4 displayed a remarkable importance in structuring fish occurrence, particularly in the paddy field and oil palm areas and was shown to be inversely correlated with species such as *M. nigriceps*, *O. vittatus* and *P. oxygastroides*. SO_4 is released into the aquatic ecosystem via natural rock weathering and anthropogenic activities, such as mining, fossil fuel burning and waste discharge. Although this parameter has no known direct effect on fish physiology, it contributes to nutrient enrichment, subsequently leading to algal bloom, which can influence fish occurrence (Hem 1985).

In the same vein, DO concentration displayed its importance in determining fish occurrence in oil palm areas, and was negatively correlated with species such as *N. notopterus*, *H. planiceps*, *T. pectoralis*, *H. nemurus* and *C. leiacanthus*. The oil palm areas contain more fresh water from Sungai Tengi and by implication has a higher DO concentration, which varies in space and time, depending on the proportion of peat water to river water. The majority of the fish species encountered in this study are narrowly adapted to low DO concentration (Beamish et al. 2003; Ng et al. 1994), therefore, some fish species naturally aggregate in areas of the oil palm with higher DO, while others prefer areas with low DO. Generally, the aerobic capacity of fish is reduced when the ambient oxygen falls below a critical point, thus increasing its dependency on anaerobic metabolism. Such scenario induces physiological stress and restricts performance, which can be lethal in extreme situations (Beamish et al. 2003). It is not surprising that oil palm areas with higher DO and pH recorded the highest species diversity and richness.

Anthropogenic activities, such as agricultural, industrial and domestic waste water discharge into water bodies have its attendant influence aquatic organisms. The direct effects of such activities include increased PO_4, NH_3-N and Cl_2 concentration, which in turn can result in algal bloom and influence fish aggregation (Ranganathan et al. 2007; Xu et al. 2015). The high Cl_2 (exceeded Malaysian recommended level), PO_4, and NH_3-N concentration recorded in peat swamp and paddy field displayed their importance in influencing fish occurrence and in both cases were negatively correlated with species such *M. nigriceps*, *O. vittatus* and *T. trichopteris*.

CONCLUSION

This study presents new data on the influences of water quality on fish occurrence in peat swamp and its converted areas in NSPSF. The findings showed a progressive decrease in fish diversity recorded in the NSPSF over the years due to peat land clearing and conversion for residential and agricultural purpose. Moreover, this study showed that peat swamp and its converted areas, namely paddy field and oil palm plantation areas have different water quality parameters associated with the fish occurrence. Thus, the results provide an important database for peat swamp and fish conservation of the NSPSF area in the future.

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