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FISH ASSEMBLAGES IN ARTIFICIAL DRAINAGE SYSTEMS ACROSS OIL PALM PLANTATION DEVELOPMENT PHASES ON PEATLAND IN SARAWAK

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ABSTRACT

Development of oil palm plantations on peatland requires drainage for water level regulation which often creates new artificial habitats for aquatic inhabitants. We assessed the changes in fish communities of the artificial drainage systems in Betong, Sarawak, Malaysia. Fish were sampled from three sampling stations at the man-made drainage from July 2013 until July 2019. A total of 1546 individuals represented by 12 species were recorded across oil palm plantation development phases. Although it is an artificial habitat, the conversion of logged peat swamp forest to cleared land reduced fish species richness by at least 25%. Not many changes were observed when the land was initially planted with palms. As the oil palm reached 2 years old, fish species richness increased and was comparable to the prior conversion phase. The fish abundance fluctuated as the peat swamp forest was being cleared, and throughout the oil palm development phases.

Keywords: blackwater, fish abundance, land use, loss forest, man-made drainage.

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INTRODUCTION

Peat swamp forest (PSF) is a waterlogged forest that grows on a layer of organic materials, such as dead leaves and plants, up to 20 m thick (UNDP, 2006). Despite having a low level of nutrients and low dissolved oxygen with acidic water, this forest is an important component of the wetland due to its unique ecosystem (Leete *et al.*, 2006). The freshwater habitat of the peat swamp is known as a habitat for diverse and interesting fish fauna that have narrow niches and a restricted range (Norhisyam *et al*., 2012).

Until 1968, only 26 fish species were known from blackwaters (colour of PSF water) in Peninsular Malaysia, of which only *Spharichthys osphromenoides* can be regarded as restricted to blackwater (Ng *et al*., 1994). In the North Selangor PSF, a total of 47 blackwater fish species have been recorded in this habitat thus, showing that PSF does support diverse fish fauna which makes it of great interest to ecologists (Davies and Abdullah, 1989). In addition, fish exhibit the highest endemicity to peat swamps compared to other faunal groups such as vertebrate species and there is no vertebrate except fish that is considered entirely dependent or restricted to peat swamp habitat (Posa *et al*., 2011). Up to 33% of the known freshwater fish species are associated with peat swamps (Kottelat *et al*., 2006; Ng *et al*., 1994; Posa *et al*., 2011). The PSFs are known to have some of the highest freshwater fish diversity in the world (Wetland International, 2010). The study by Ng *et al*. (1994) reported that diverse and interesting fish fauna with narrow niches and restricted ranges were present in PSFs. According to Rahim and Esa (2006), most of the fishes that inhabit the peat swamp system are those species that are tolerant to low oxygen conditions and acidic water that is rich in decaying organic matter. About 66% of the total fish found in the North Selangor peat swamp have the ability to breathe atmospheric air, whether they are air breathers or often swim near the surface (Ng *et al*., 1994). Additionally, blackwater, characterised

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by its black appearance or tea-coloured water, acidic and low dissolved oxygen has been regarded as an extreme and inhospitable habitat and, thus was poorly explored in the early days.

Over the past few decades, the conversion of PSF for oil palm agriculture has been common, particularly in the Southeast Asia region (Miettinen *et al*., 2016). Peatland has become the potential land for oil palm cultivation since the land mineral soil has become scarce. By the year 2018, about 657 000 ha of peatland in Sarawak were planted with oil palm, which covered about 34% of the total oil palm planted area in the region (Wan Mohd Jaafar *et al*., 2020). Fewer studies related to the fish community are being carried out in oil palm plantations in Malaysia. Dosi *et al.* (2019) conducted a fish study in Sungai Kulak of Tinbarap Conservation Area (TCA), located in Tinbarap Estate Miri, Sarawak, and documented a total of 106 fish representing 13 species and seven families. Another study by Chong (2014) on the diversity and abundance of freshwater fish fauna in various landscapes (drainage systems and streams or rivers within conservation areas) within oil palm plantations recorded a total of 503 fish represented by 35 species. From the species caught, two species were endemic to Borneo (namely, *Nematabramis everetti* and *Barbonymus collingwoodii*), three exotic species [*Cherax quadricarinatus* (red-claw crayfish), *Macrobranchium rosenbergii* (giant freshwater prawn) and *Oreochromis niloticus* (tilapia)], while the remaining were native species. Both studies recorded the dominance of Cyprinidae in the conservation area in oil palm plantations which are similar to other peat swamp habitats (Chong, 2014; Dosi *et al*., 2019).

Being a waterlogged forest with a high water table under natural conditions, the removal of excess water to lower the water table as required for oil palm cultivation is essential before cultivating oil palm on peatland (Lim *et al*., 2012). Therefore, the drainage network is often established for water table regulation which will create a new artificial habitat for aquatic inhabitants, particularly fish. Thus, a fish study covering an area in artificial habitat in response to the conversion of drained peat swamp forest to oil palm monoculture was conducted. This study hypothesises that the fish community in the artificial drainage system changes throughout the development phases in relation to the change in water quality and habitat conditions.

MATERIALS AND METHODS

Study Site

The aquatic fauna study was focused on the fish community and assemblages throughout the oil palm development phases in Ladang Lingga 2, Betong, Sarawak, Malaysia (*Figure 1*).

The sampling sites selected were located at the man-made drainage within the area with ongoing development activity. There was no river present in this development area hence the fish study was conducted at artificial drainage systems which were constructed to control water-table. However, the drainage system is connected to the adjacent mature oil palm plantation and Lupar River. Lupar River is located 1 km apart from the oil palm plantation and is covered with peat swamp forest that acts as a buffer

Figure 1. *Location of the fish fauna sampling points in Ladang Lingga 2, Betong Division, Sarawak, Malaysia.*

zone. The drainage system is very important for water-table management in oil palm development on peat to get high and sustainable yield production and to reduce carbon dioxide emission (Othman *et al*., 2011). Fish sampling was initiated at the early drainage (main and collection drains) system that was constructed together with the road system. Once the road and drainage systems were established, the area was cleared and the field drain was created. After the clearing was done, the planting was immediately commenced with oil palm. As the area was planted with oil palm, the fish study was divided into three different drainage systems: Collection drain (St. A), perimeter drain (St. B), and main drain (St. C). Fish sampling was conducted throughout the oil palm plantation development phases, from July 2013 to July 2019, with the frequency of every three months at all stations. Sampling before oil palm planting was carried out in two phases: Drained peat swamp forest (DPSF) and cleared land (CL) that was converted to oil palm plantation. Meanwhile, samplings after planting involved five phases of the oil palm development phase, namely, 1 year oil palm (YOP), 2-YOP, 3-YOP, 4-YOP and 5-YOP.

Fish Sampling

Fish were sampled using three layer gill nets, monofilament gill nets (mesh size of 5.5 and 2.5 cm), and kick nets. The gill nets were deployed for three days and two nights. Fish species were identified *in-situ* while fishes that were unable to be identified were preserved in formalin (10%) and brought back to the laboratory for further identification. After identification, fish samples were transferred to ethanol (70%) for long-term preservation. Fish identification was carried out at the species level with reference to Froese and Pauly (2019), Kotellat and Whitten (1993), and Inger and Chin (2002). The Conservation Status of the fish was listed based on The IUCN Red List of Threatened Species Version 2021-3 (IUCN, 2022).

In-situ Parameter Water Quality Sampling

Triplicate readings of water temperature, dissolved oxygen (DO), pH and conductivity were measured at the subsurface of all sampling stations using YSI 6600 V202 Multi-parameter Water Quality Sonde (YSI Inc., Ohio, USA).

Statistical Analyses

One-way analysis of variance (ANOVA) was used to determine the significant differences in environmental data, water quality, species richness and abundance of fish community among development phases, with a *posteriori* Tukey HSD test at a significance level of 95% (Calloway *et al*., 2017; Gyawali *et al*., 2013; Ndungu *et al*., 2013; Zakeyuddin *et al*., 2016). These analyses were computed using SPSS 17.0 Software. Variation in the fish community of different oil palm plantation development phases was investigated using the ordination method. Non-metric multidimensional scaling (NMDS) was carried out using the metaMDS function from the vegan package in R version 3.6.3. Sites that were most similar to one another in species composition are closest together on the NMDS plot (Oksanen *et al*., 2015). Subsequently, the statistical difference between groups was tested using the function "ANOSIM" from the vegan package.

RESULTS AND DISCUSSION

A total of 1546 fish representing 12 species belonging to six families (*Table 1* and *Figure 2*) were recorded throughout this study. Meanwhile, Khairul-Adha *et al.* (2009) recorded 36 species of fish from brownish and blackish water habitats of Batang Kerang in Balai Ringin, Sarawak. Rahim *et al.* (2009) also studied the fish fauna in blackwater and waters originating from PSFs at Batang Kerang, Balai Ringin, Sarawak and reported 12 species of fish from 12 families, and the Kissing Gourami fish was the dominant species. Hassan *et al.* (2010) found seven out of 15 fish species were from a water body with peat-like characteristics in Nanga Merit area and Giam *et al.* (2012) recorded 13 fish species from the peat swamps of Rajang and Sadong in Sarawak. Sule *et al.* (2016) stated that a total of 198 peat swamp species have been recorded in Malaysia whereby 114, 49, 13, 58, 31 and 40 species were recorded from North Selangor PSF, PSF of Perak, PSF of Johor, PSF of Pahang, East Peninsular Malaysia (parts of Pahang and Terengganu), and East Malaysia (Sarawak and Sabah), respectively.

The most dominant fish family was Anabantidae with 51.4% of the total number of individuals caught followed by Helostomatidae (22.8%), Osphronemidae (17.0%), Clariidae (5.1%), and finally, Channidae (3.8%). The least dominant fish family in this area was Siluridae, with 0.1% of the total number of fish caught. Similarly, as reported by Rahim *et al*. (2009), these families of fish species are occupied with accessory respiratory organs and suprabranchial cavities that assist them in adaptation to water with low concentrations of dissolved oxygen and high acidity. Of the 12 species caught, *Anabas testudineus* was the most abundant comprising 51.4% of the total number of fish caught, followed by *Helostoma temminckii* (22.8%), *Trichopodus trichopterus* (16.8%), *Clarias leiacanthus* (2.3%), *C. meladerma* (2.0%), *Channa striata* (1.8%) and *C. lucius* (1.5%). Meanwhile, fishes such as *Channa bankanensis*, *Clarias nieuhofii*, *Trichopodus pectoralis*,

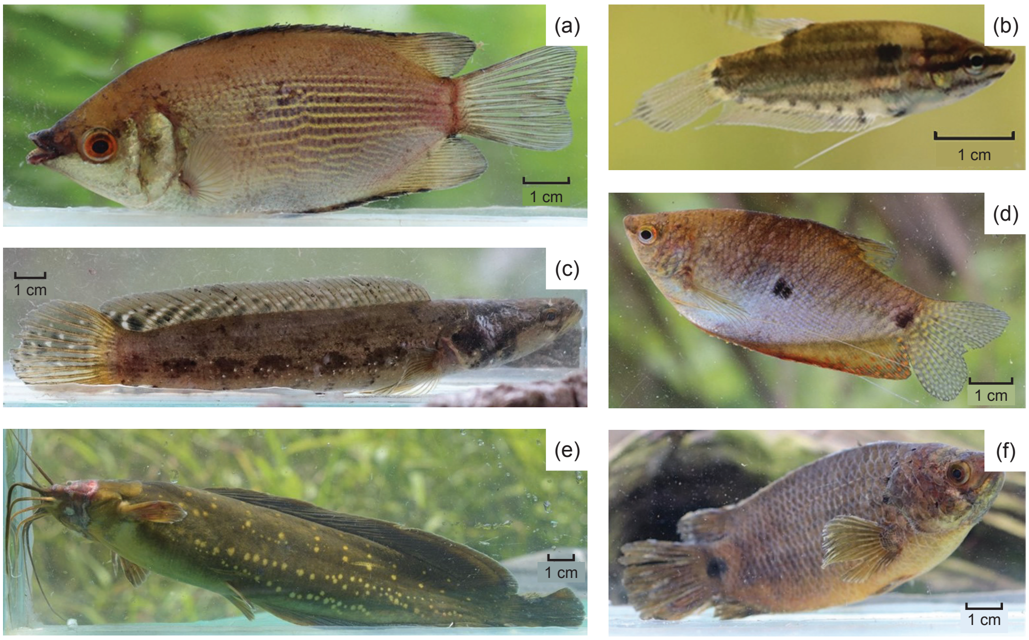


Figure 2. Fish species recorded from the study: (a) Helostoma temminckii, *(b)* Trichopsis vittata, *(c)* Channa lucius, *(d)* Trichopodus trichopterus, *(e)* Clarias leiacanthus *and (f)* Anabas testudineus.

TABLE 1. LIST OF FISH SPECIES, RELATIVE ABUNDANCE AND THEIR CONSERVATION STATUS RECORDED AT LADANG LINGGA 2, BETONG, SARAWAK

Family name	Common name	Scientific name	IUCN	Relative abundance (%)	Oil palm development phase						
					DPSF	CL	1YOP	2YOP	3YOP	4YOP	5YOP
Anabantidae	Climbing Perch	*Anabas testudineus*	LC	51.4	+	+	+	+	+	+	+
Channidae	Bangka Snakehead	*Channa bankanensis*	LC	0.5	+	-	-	+	-	-	+
	Forest Snakehead	*Channa lucius*	LC	1.5	+	+	+	+	-	+	+
	Striped Snakehead	*Channa striata*	LC	1.8	+	+	+	+	+	+	+
Clariidae	Forest Catfish	*Clarias leiacanthus*	LC	2.3	+	+	+	+	+	+	+
	Blackskin Catfish	*Clarias meladerma*	LC	2.0	+	+	+	+	+	+	+
	Slender Catfish	*Clarias nieuhofii*	LC	0.8	+	+	+	+	-	+	-
Helostomatidae	Kissing Gourami	*Helostoma temminckii*	LC	22.8	+	+	+	+	+	+	+
Osphronemidae	Snakeskin Gourami	*Trichopodus pectoralis*	LC	0.1	-	-	-	-	-	+	-
	Three Spot Gourami	*Trichopodus trichopterus*	LC	16.8	-	+	+	+	+	+	+
	Croaking Gourami	*Trichopsis vittata*	LC	0.1	-	-	-	-	-	-	+
Siluridae	Ompok Catfish	*Ompok leiacanthus*	NT	0.1	-	-	-	-	-	-	+

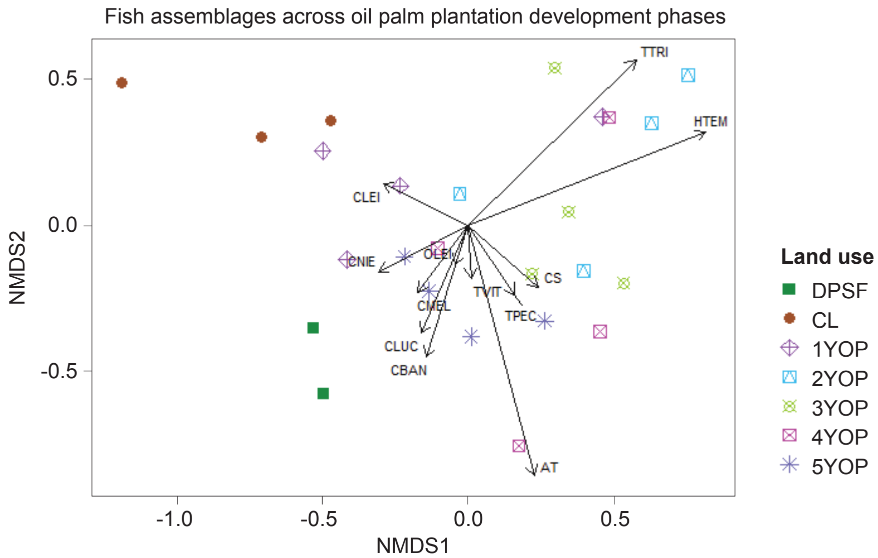
Note: Conservation Status based on the IUCN Red List of Threatened Species Version 2021-3 (IUCN, 2022): NT - near threatened (includes LR/nt - lower risk/near threatened); LC - least concern (includes LR/lc - lower risk, least concern). For oil palm development phase: DPSF - drained peat swamp forest; CL - cleared land; 1YOP - 1 year oil palm; 2YOP - 2 years oil palm; 3YOP - 3 years oil palm; 4YOP - 4 years oil palm; and 5YOP - 5 years oil palm. "+" denotes the presence of species and "-" denotes the absence of species in the study area.

T. vittate and *Ompok leiacanthus* were considered least dominant as they only contributed less than 1% of the total number of individuals caught. Fish species recorded in this study were similar to those recorded in the North Selangor peat swamp forest Selangor, Paya Beriah peat swamp forest Perak, Southeast Pahang peat swamp forest and Sarawak peat swamp forest (Ahmad *et al*., 2005; 2013; Ismail *et al*., 2013; Khairul-Adha *et al*., 2009; Rezawaty, 2004; Shah *et al*., 2006; Siow *et al*., 2013).

Non-metric multidimensional scaling (NMDS) ordination using Bray-Curtis similarities was used to summarise the variations that may occur within the fish assemblage in the oil palm plantation throughout the sampling period (*Figure 3*). The ordination displayed DPSF and CL were grouped on the left of the graph while 1YOP, 2YOP, 3YOP, 4YOP and 5YOP were clustered to the right, which indicated a gradual change in fish assemblage structure in the oil palm plantation throughout the oil palm development phases. This variation was also found to be significant by ANOSIM test among all sites at $p < 0.05$.

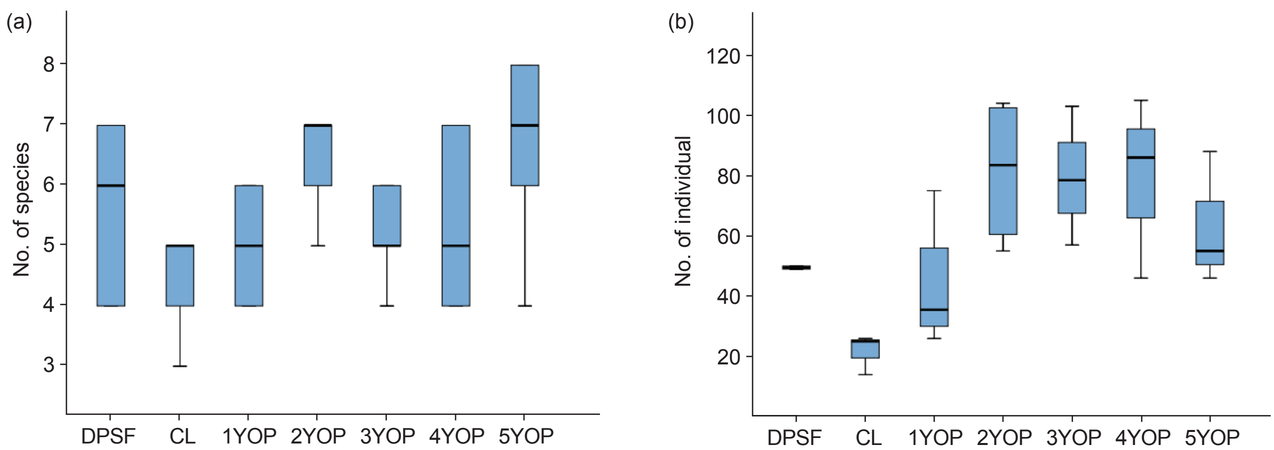
Seven fish species were recorded from the aquatic habitat of drained peat swamp forest. As the area was being cleared, fish species richness and abundance decreased by at least 25% and 48% respectively (*Figure 4*).

There is no significant difference in fish species richness at the artificial drainage system along the oil palm development phases ($F_{(6,18)} = 1.404$, $p = 0.267$). After planting, during 1YOP, species richness showed an increment by at least 10% compared to the CL phase but remained lower by at least 14% as compared to DPSF. Meanwhile, fish abundance increased by at least 48% as compared to DPSF and double that of those recorded during the CL phase. As it reached 2YOP, fish species richness was comparable to the DPSF phase and more than those recorded during the CL phase. The abundance of fish ($F_{(6, 18)} = 4.430$, $p=0.006$) was significantly greater in 2YOP (mean = 81 individuals), 3YOP (mean = 75 individuals), and 4YOP (mean = 80 individuals) than CL (mean = 21 individuals), DPSF (mean = 50 individuals), 1YOP (mean = 43 individuals) and 5YOP (mean= 61 individuals). Fish abundance was doubled as compared to the DPSF phase and was fourfold greater than in the CL phase.



Note: Oil palm development phase: DPSF - drained peat swamp forest; CL - cleared land; 1YOP - 1 year oil palm; 2YOP - 2 years oil palm; 3YOP - 3 years oil palm; 4YOP - 4 years oil palm; and 5YOP - 5 years oil palm.

Figure 3. Non-metric Multidimensional Scaling (NMDS) ordination of fish assemblage in different oil palm plantation development phases.



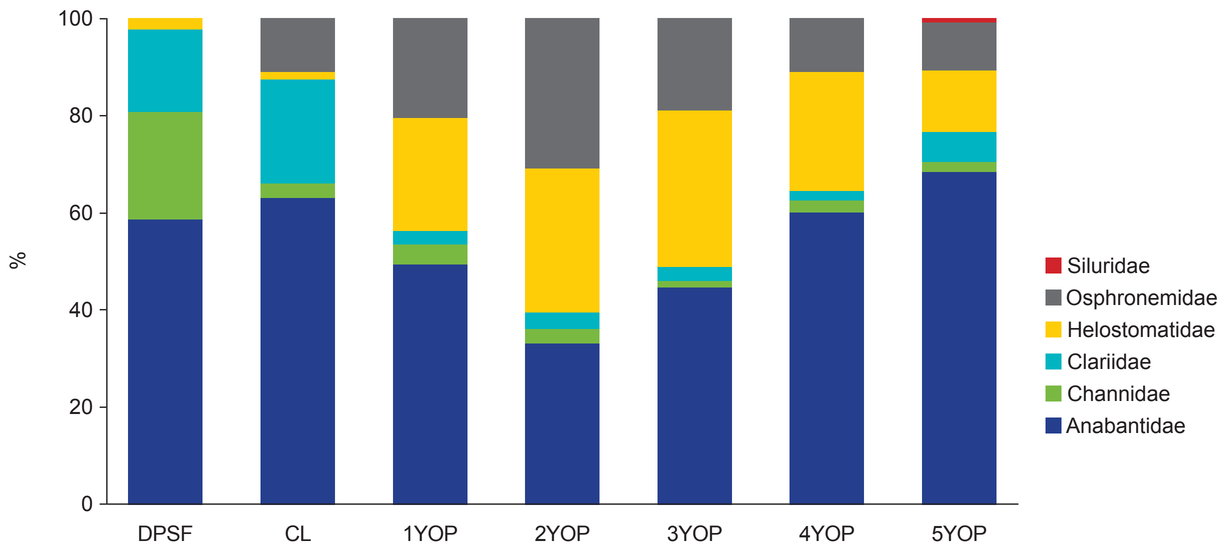
Note: Abbreviation for oil palm development phase: DPSF - drained peat swamp forest; CL - cleared land; 1YOP - 1 year oil palm; 2YOP - 2 years oil palm; 3YOP - 3 years oil palm; 4YOP - 4 years oil palm; and 5YOP - 5 years oil palm.

Figure 4. Boxplots of fish, (a) species richness and (b) abundance across oil palm plantation development phases.

Fish composition in each development phase of the oil palm plantation shows that Anabantidae was dominant during each phase (*Figure 5*). Helostomatidae constituted a very small percentage of the population before oil palm planting (*i.e.*, during DPSF and CL phase). After oil palm planting (1YOP-5YOP) the proportion increased. Likewise, Osphronemidae which was only recorded after the forest was cleared showed increments in the community composition as palms aged. In contrast to Helostomatidae and Osphronemidae, the composition of Channidae was lower after conversion and remained low after oil palm planting. *Channa bankanensis* for instance was recorded during the DPSF phase but was not recorded as the forest was being cleared. It was until the palm reached 2YOP that this species was recorded again. Similarly, the composition of Clariidae was lower compared to DPSF and CL phases after oil palm planting. Siluridae which was represented by *Ompok leiacanthus* was only recorded during the 5YOP which suggests that it might have entered the plantation drainage network from the nearby river.

One-way ANOVA results show significant differences in water temperature, pH, dissolved oxygen, and conductivity throughout the oil palm development phases (*Table 2*). After planting with oil palm, the pH of the water became more acidic, water temperature and dissolved oxygen were lower, and conductivity was higher. This may be the reflection of agricultural activities in the oil palm plantation similar to those reported in the MAAH oil palm plantation in Selangor by Azizan *et al*. (2021). Shabalala *et al*. (2013) also reported high conductivity in the oil palm plantation could be due to the application of fertiliser on the palm trees. These results indicate that fish inhabiting the water habitat in oil palm plantations were able to tolerate the acidic, low dissolved oxygen and water temperature and higher conductivity.

The fish study was conducted at artificial drainage systems as the river is not present in this area, similar to those conducted by Azizan *et al*. (2021) in drains in oil palm plantations in the southern part of Selangor. This artificial drainage system is connected with adjacent mature oil palm plantations and rivers (1 km apart). In this artificial drainage system, a total of 12 species of fish were recorded across the development phases, of which all seven species of the DPSF fish species continued to be recorded after the forest conversion to oil palm plantation, while four fish species were additional species from DPSF species, appearing following clearing process and planting of oil palm. The presence of these species might be due to the drainage system in this plantation being connected to an adjacent mature oil palm plantation drainage system. Azizan *et al*. (2021) recorded five fish species in an oil palm plantation in the southern part of Selangor with the species also recorded in this study. A fish study conducted by Chong (2014) in oil palm plantations in different ecosystems including rivers within peat swamp conservation areas and oil palm drainage recorded 35 species of fish. Also, Dosi *et al*. (2019) conducted a fish study at a river located within the peat swamp conservation area and recorded a total of 13 species. Both studies showed that the family Cyprinidae was the most diverse species recorded at rivers within conserved peat swamp forests in oil palm plantations. Family Cyprinidae



Note: Abbreviation for oil palm development phase: DPSF - drained peat swamp forest; CL - cleared land; 1YOP - 1 year oil palm; 2YOP - 2 years oil palm; 3YOP - 3 years oil palm; 4YOP - 4 years oil palm; and 5YOP - 5 years oil palm.

Figure 5. Percentage of fish abundance according to family recorded across different phases of oil palm plantation developments.

TABLE 2. *In-situ* WATER QUALITY PARAMETERS RECORDED ACCORDING TO DIFFERENT OIL PALM DEVELOPMENT PHASES

Parameter	Oil palm development phase							*p*-value
	DPSF	CL	1YOP	2YOP	3YOP	4YOP	5YOP	
Cond (mS/cm)	0.074 ± 0.001^{a}	0.89 ± 0.001^{a}	0.091 ± 0.001^{a}	0.094 ± 0.001^{ab}	0.119 ± 0.005^{b}	0.178 ± 0.008^{c}	0.260 ± 0.005^{d}	0.01
Temperature (°C)	31.5 ± 0.80^{bc}	30.1 ± 0.45^{b}	31.5 ± 0.24^{bc}	31.9 ± 0.21^{c}	30.9 ± 0.34^{bc}	27.7 ± 0.19^{a}	28.3 ± 0.30^{a}	0.01
pH	4.2 ± 0.03^{b}	4.3 ± 0.03^{b}	4.4 ± 0.014^{b}	3.76 ± 0.06^{a}	3.81 ± 0.034^{a}	3.81 ± 0.07^{a}	3.9 ± 0.06^{a}	0.02
DO (mg L^{-1})	0.98 ± 0.56^{a}	2.39 ± 1.74^{b}	4.32 ± 0.75^{d}	3.65 ± 2.33^{cd}	2.84 ± 1.59^{bc}	1.29 ± 0.79^{a}	1.18 ± 1.63^{a}	0.01

Note: Means with the same letters (in alphabet) in the same row are not significantly different with $p>0.05$. Abbreviation for oil palm development phase: DPSF - drained peat swamp forest; CL - cleared land; 1YOP - 1 year oil palm; 2YOP - 2 years oil palm; 3YOP - 3 years oil palm; 4YOP - 4 years oil palm; and 5YOP - 5 years oil palm.

was found to commonly dominate the rivers in Southeast Asia (Rahim *et al*., 2009). The diversity and composition of the freshwater fish fauna are associated with several factors in the streams and rivers such as availability of food sources, topography, physicochemical properties of water, and water current (Rahim *et al*., 2009). Freshwater fishes that can adapt to the environment are likely to have a higher possibility of surviving (Chong, 2014). The increment of species richness and abundance in the artificial drainage habitat of a newly developed oil palm plantation on peatland after planting could be due to the extension of the drainage network, which increases the connectivity of fishes from the nearby plantation drainage network and river to the newly created habitat.

It was different for artificial drainage systems whereby the family Clariidae (air-breathing Catfish) are the most diverse species recorded during DPSF, CL, and oil palm phases (except 3YOP and 5YOP) with three species. In Borneo, catfishes are the most abundant component of freshwater fish fauna together with the family Cyprinidae and they also tend to display an overwhelming rate of endemic species (Kottelat and Whitten, 1993). Catfishes of the *Ompok leiacanthus* recorded in this study were listed as Near Threatened species under IUCN Red List. Overall, the species recorded consisted of hardy species that can tolerate harsh water conditions. In this study, climbing perch, *Anabas testudineus*, was the most abundant fish species recorded along the development phases followed by Kissing Gourami, *Helostoma temminckii,* and Three Spot Gourami, *Trichopodus trichopterus*, and these species are air-breathing species. Air-breathing fishes are bimodal breathers where their organ enable them to obtain oxygen from atmospheric air and also when in water (Nelson, 2014). During the oil palm phases, all these species are present in all drainage systems, *i.e*., the main drain and collection drain. The dominance of *Anabas testudineus* could be related to its ability to tolerate low oxygen levels and turbid water conditions, thus enabling its succession in the new habitat, especially after forest clearance (Bhattacharjee *et al*., 2009; Habib and Hassan, 1994). This species is also equipped with the labyrinth, thus enabling it to take oxygen from the air and can tolerate turbid stagnant waters (Kottelat, 2001; Velmurugan *et al*., 2015).

Low dissolved oxygen (DO) levels in the drainage system might be due to high conductivity caused by the agricultural activity after planting with oil palm. DO value in this study was recorded lower as compared to the study conducted by Gandaseca *et al*. (2015) at Sibu and Mukah District, Sarawak. Gandaseca *et al*. (2015) found that rivers at newly planted oil palm plantations recorded DO values of 3.37+0.07 at Sibu and 3.86+0.10 at Tatau while at undisturbed peat swamp forest recorded 4.98+0.14 at Pandan and 5.02+0.09 at Sepadok. Water temperature decreased and became cooler after the drainage system was shaded by the palm canopy. Water temperature is influenced by the lack of canopy cover, its shallowness and stagnant water condition (Gandaseca *et al*., 2015). In addition, *A. testudineus* possesses a special accessory air-breathing organ, situated just above the gills in a large extension on the upper part of each gill chamber, which facilitates the utilisation of atmospheric air for respiration (Hughes *et al*., 1973). During the larval and juvenile stage, *A. testudineus* prefers to feed on plankton while in the adult stage, they mainly feed on insects, invertebrates, small fish, and plants (Davenport and Matin, 2006). *Helostoma temminckii* constitutes a very small percentage of the fish community before oil palm planting. However, after oil palm planting starting from 1YOP to 5YOP they proliferated to a larger number. It feeds on a variety of plants and animals including green algae, zooplankton, and aquatic insects near the water surface (Rainboth, 1996; Ukkatawewat, 2005). *Trichopodus trichopterus* was the third most abundant species in this study. This species is small and native to Southeast Asia (Knight, 2010). They successfully colonised new aquatic habitats because of their wide environmental tolerance, ability to colonise anthropogenically disturbed habitats, tropic opportunism, and fast growth rate (Pinter, 1986). In addition, the presence of *T. trichopterus* after the clearing of land could be influenced by the forming of feeding aggregations for short-term temporal patterns of resource availability (Azizan *et al*., 2021; Syarifuddin and Kramer, 1996). Dosi (2017) found that an artificial drainage system in oil palm plantation on peat recorded high water temperature, turbidity, total suspended solid (TSS), conductivity, biochemical oxygen demand (BOD), pH and nitrite but low dissolved oxygen. This could be related to agricultural activities and fish species that are recorded in oil palm plantation drainage systems can tolerate to these water quality conditions.

After conversion phases, four additional species of fish have been recorded from DPSF phase fish species: *Trichopodus trichopterus* at CL, *T. pectoralis* at 4YOP and *T. vittata* and *Ompok leiacanthus* at 5YOP. The appearance of additional fish species in this study might be due to the connection between the drainage system and Lupar River nearby. Fish abundance slightly decreased after 4YOP and this could be attributed to the vegetation removal which resulted in the loss of vegetation cover responsible to shade the water surface and subsequently increase the water surface exposure to sunlight, which then increases the water temperature. In addition, dredging activities might have resulted in the increase in sedimentation of water habitat during the process and thus negatively affecting the fish. It is also important to note that prior to conversion, *i.e.*, during the DPSF phase, samplings were conducted at the artificial drainage system that was previously made to regulate the water table as preparation for oil palm planting. During this phase, the drainage network has been established but not extensive. During the CL phase, more areas were dredged to extend the drainage network. Even though the extension of the drainage network creates new habitat for fish, the reduction in species richness and abundance could be attributed to the vegetation removal which resulted in the loss of vegetation cover responsible for shading the water surface and subsequently increasing the water surface exposure to sunlight, therefore, increase the water temperature.

CONCLUSION

This study assesses the response of fish assemblages in artificial drainage systems as the drained peat swamp forest was being converted to oil palm monoculture. Species richness and abundance fluctuated as forest area was cleared and throughout the oil palm development phases. However, after oil palm planting, fish abundance showed an early recovery as the palm reached one year old meanwhile fish species richness recovered as the palm reached two years old. Letting natural plants grow along the drainage system for better water quality creates habitats for aquatic and wetland carnivorous fauna.

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