Penerbit Akademia Baru

Journal of Advanced Research in Applied Sciences and Engineering Technology

Journal homepage: www.akademiabaru.com/araset.html
ISSN: 2462-1943

The Effects of Oil Palm Plantation on Fish Composition in Selangor Peatlands, Malaysia

Siti Noor Fitriah Azizan[1,2,3,*], Minh Nhat Huynh [2,3], Rory Padfield[2,3,4], Stephanie Evers[3,5], Kosuke Noborio[6], Hirofumi Hara[7]

1 Graduate School of Agriculture, Meiji University, 1-1-1 Higashi-Mita, Tama-ku, Kawasaki 214-8571, Japan
2 Malaysia Japan International Institute of Technology, Universiti Teknologi Malaysia, Kuala Lumpur 54100, Malaysia
3 Tropical Catchment Research Initiative (TROCARI), Kuala Lumpur, Malaysia
4 School of Earth and Environment, University of Leeds, Leeds, United Kingdom
5 School of Natural Sciences and Psychology, Liverpool John Moores University, Liverpool, United Kingdom
6 School of Agriculture, Meiji University, 1-1-1 Higashi-Mita, Tama-ku, Kawasaki 214-8571, Japan
7 Department of Biotechnology, Graduate School of Agricultural and Life Sciences, The University of Tokyo, 1-1-1, Yayoi, Bunkyo-ku, Tokyo 113-8657, Japan

ABSTRACT

The cultivation of oil palm on peat swamps in Malaysia has changed the water quality and aquatic ecosystems. The fish species composition and water quality conditions were determined at a disturbed peat swamp, i.e., oil palm plantation, in Kuala Langat peat swamp reserve forest, Selangor. Fishes were collected via gill net in five selected drains during dry and wet seasons between August 2014 and January 2015. *In-situ* (electrical conductivity (EC), dissolved oxygen (DO), pH, turbidity and temperature) and *ex-situ* (dissolved organic carbon (DOC)) physicochemical parameters of water quality were measured bimonthly. The length-weight relationship (LWR) of fish related to seasonal and spatial variation was also examined. A total of 336 individuals belonging to five families of fish were found with *Trichopodus trichopterus* and *Anabas testudineus* were the two abundant species. The DOC ranges at drainage with established palm trees area (i.e., 15-yo(A) 1stG, 3-yo 2ndG, and 9-yo 2ndG) was much greater than at cleared-felled (CF 2ndG) suggested that these plantation areas have carbon leaching due to high supply of labile leaf litter produced by palm trees. The observed EC and temperature were 5% higher in the dry season compared to the wet season. The *A. testudineus* showed highly adaption with high DOC level particularly in 15-yo 1stG, and 9-yo 2ndG drains during the wet season. The LWR showed that *A. testudineus* was in a desirable growth rate and demonstrated they were doing better compared to *T. trichopterus* in the oil palm plantation system.

Keywords:
Fish composition; oil palm plantation; water quality; tropical peat swamp

Received: 20 October 2021 **Revised: 27 November 2021** **Accepted: 17 December 2021** **Published: 18 December 2021**

1. Introduction

Freshwater fish are an extremely diverse group that has evolved to a wide range type of habitats studied around the world. Besides being the source of protein, fish also play an important role in

* *Corresponding author.*
E-mail address: azizanf@meiji.ac.jp

https://doi.org/10.37934/araset.25.1.1936

maintaining the ecological balance in the aquatic ecosystem [1]. The population and composition of the fish community have been used as an indicator for water quality assessment for river and water resources due to anthropogenic causes [2-5]. The major threats to fish biodiversity are intense. They have been relatively well documented: the destruction of habitats, agricultural development, overexploitation, invasion by exotic species, pollution, including the worldwide phenomena of eutrophication and sedimentation [6]. Furthermore, the species diversity of an ecosystem is frequently linked to the amount of living and non-living organic matter present in it [7].

The tropical peat swamp forest system is one of the most unusual biomes in the tropics. The waters of the peat swamp system generally have low oxygen content and high levels of humus and tannins, and, as a result, are dark brown to black in colour [8,9]. The low pH (approximately 3.5 [10]) is due to the oxidation of sulphate soils as well as the presence of humic acid, tannins, and other organic acids [11]. Southeast Asian peat swamp forest system support unique and endemic blackwater fish species [12-17]. However, since the 1970s, large areas of peat swamp in Southeast Asia have been cleared and subjected to artificial drainage in response to agricultural demand [18] with negative impacts on the high acidity tolerance blackwater species.

Indonesia and Malaysia are two leading countries of the world's palm growers, which produce 49% and 38%, respectively, in the world [19]. Malaysian oil palm industry has grown rapidly over the years to become the second world's largest producer and exporter of palm oil and its products [20]. Consequently, the growth of the palm oil industry has led to the development of Malaysia's peat swamp forest to agricultural lands. The conversion of the peat swamp system to oil palm cultivation has a negative impact on the water quality in watersheds [27,28]. The construction of drains that cause erosion will result in poor water preservation and leads to water deterioration. The use of agrochemicals (i.e., pesticides and fertilizers) in oil palm plantations on peat soil, having high porosity, may cause fast leaching of nutrients into the shallow groundwater. In most cases, the fish community is mainly dependent on aquatic vegetation for breeding ground and feeding habitat [11,21-23]. However, the conversion of oil palm plantations has changed the water quality and physical habitat directly, thus, associated mainly to alteration of fish composition [24]. Furthermore, pesticides and fertilizers application alternated morphologies in scale, gill, and fish blood [25].

Many studies have investigated to update current status of fish community structure, species composition in Malaysia's freshwater ecosystem, including peat swamp forest system [16,26–32]. However, fewer studies examine succession responses to different environmental conditions resulting from disturbed oil palm plantations [33,34]. This study aims to identify fish composition and their relationship to the water quality in disturbed peatland, i.e., oil palm plantation. Our study addressed three questions: 1) how the block of plantations (i.e., 1st generation and 2nd generation; referring to cycle of the oil palm plantation, which 1st generation was within 25 years old of plantation and 2nd generation was for replanting plantation after 25 years old) influence the water quality and fish composition in their side drains, 2) how well-being of fish (by assessing their length-weight relationship) of two abundance species in oil palm plantations.

2. Methodology

The study area was undertaken at Malaysia Airport Agriculture and Horticulture Sdn Bhd (MAAH) oil palm plantation that located adjacent to Kuala Langat PSF in the southern part of Selangor. The MAAH plantation are about 10,000 ha and was previously a swamp forest managed for timber production before being converted into an oil palm plantation in 1977. The location of five selected drains is shown in Fig. 1 and described in Table 1. The plantation is located side by side to the peat swamp forest. Therefore, the drainage in the plantation area receives water from swamp forests nearby. The water is black in colour, slow-flowing, and highly acidic. The bottom of the drainage was peat soil: decomposed materials from tree branches and leaves of oil palm, and submerged vegetation. Five drains in the plantation were chosen according to the different ages of oil palm planted as they have different depths of peat and prefer different water quality. Also, the drains selection could be referring to preferable habitat conditions for different fish species. The plantation received low rainfall in the middle of a year (February 2014 to August 2014) and high rainfall at the end of a year (September 2014 to January 2015), as shown in **Supplementary 1**.

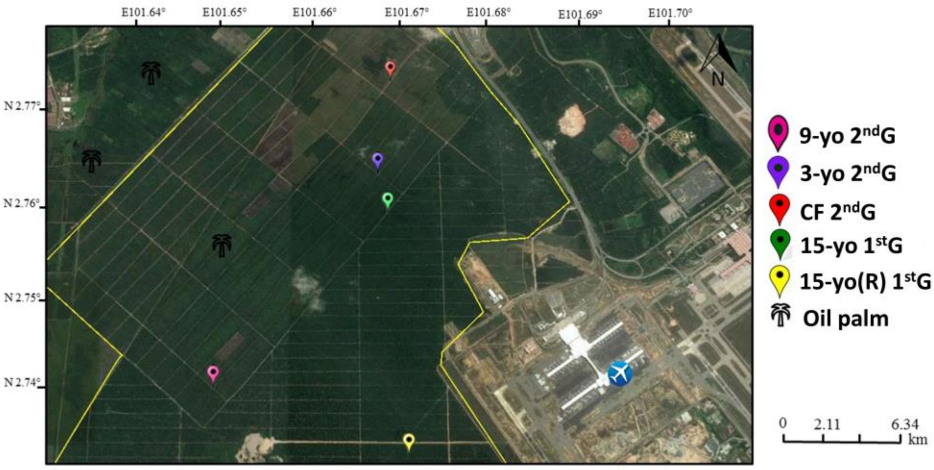

Fig. 1. Sampling drains of MAAH oil palm plantation Selangor, Malaysia. (Source: Google earth, accessed on January 15, 2016).

Table 1
Description of sampling drains at oil palm plantation.

Sampling drains	site description
CF 2ndG	Drain side of cleared-felled, second-generation plantation (02°46.407'N 101°40.043'E). The drain is side to the area (block of plantation) that was felled in 2013 and considered as one completed a 25-year cycle of first-generation oil palm. New palm oil trees were planted in mid-2014. The shallowness of the peat in this area (less than 1m) is explained by the following: either i) peat subsidence from the 25-year cycle of palm oil cultivation has occurred or ii) the area is located at the edge of the peatland dome. The area was flooded during the wet season with high rain intensity in November and December 2015. The water was mostly clear as some aquatic plants and algae nominated by *Myriophyllum* spp. and *Eunotina* spp. Drain's width and depth are approx. 6 and 2.5m, respectively.
3-yo 2ndG	Drain side of 3 years old, second-generation plantation (02°45.730'N 101°39.946'E). The drain is side to the plantation's area that was replanted in 2010. This plantation's area has been planted twice; thus, it is considered a second-generation (for three years). This drain was chosen as it is connected in between the CF 2ndG drain and 15-yo 1stG. Drain's width and depth are approx. 5 and 2m, respectively.
9-yo 2ndG	Drain side of 9-years old, second-generation plantation (02°44.316'N 101°38.911'E) The drain is side to the plantation's area that has been replanted in the year 2006. This plantation's area has been planted twice; thus, it is considered a second-generation (for nine years). This drain was located further within the oil palm plantation, a far away from both another second-generation drainage (3-yo 2ndG and CF 2ndG).
15-yo 1stG 15-yo(R) 1stG	Drain side of 15-years old, first-generation plantation. Both drains of 15-yo 1stG (02°45.450'N 101°40.007'E) and 15-yo(R) 1stG (02°43.981'N 101°40.075'E) are located side to the plantation's area that has first planted in 2000. (R) was represented the drain located

	near to the runway in the middle of the plantation. Both plantation's area is in their first generation of planting cycle.

Note: oil palm replanting is normally carried out after about 25 to 30 years of economic life span. The first-generation of this study refers to the area cultivated of oil palm from natural PSF, while the second generation area has been planted twice. The second-generation plantation considered more than 25 years old of peat soil disturbance.

2.2 Physicochemical Water Quality

Five *in-situ* (electrical conductivity (EC), dissolved oxygen (DO), pH, turbidity and temperature) and *ex-situ* (dissolved organic carbon (DOC)) physicochemical parameters of water quality was measured bimonthly from December 2013 to March 2015 for three selected drainage; 15-yo 1stG, CF 2ndG, 3-yo 2ndG, and 9-yo 2ndG in oil palm plantation. Electrical conductivity, DO, pH, and temperature measurements were undertaken using a handheld digital multiparametric YSI Pro Plus [3], [4]. Turbidity was measured using a 2100Q portable turbidimeter (HACH, U.S.A). The water samples at all *in-situ* water measurement were collected for DOC analysis. The water samples were filtered (0.45 µm microspore membrane filter paper) and analyzed using a spectrolyser device (S::CAN, Austria, Vienna). Those parameters were selected because they are among the major importance in fish life [35].

2.3 Fish Sampling and Identification

In the selection of fish sampling method, biological and environmental factors that influence sampling efficiency was considered. The selection of the sampling method is also based on habitat characteristics and target species. Environmental factors considered were the size, depth of the water body sampled, water velocity, and previous and current weather conditions. Due to low flow conditions and to avoid disturbance of the biological factors in the channels, passive techniques, as opposed to active techniques, were implemented in this study. Gill nets were chosen as suggested by Ng *et al*., [36].

Fish samples were collected two times during the study period (dry and wet seasons). Fish sampling was done at the oil palm plantation in August 2014 (dry season) and December 2014 (wet season), while at the forest system, the fish sampling was taken in March 2015 (dry season) and January 2015 (wet season). At each sampling drain, two gill-nets with one-inch mesh size and one net with two inches mesh size were placed perpendicular to the drain at the angle to get 10 m. The nets were placed 15 meters apart. Overall, 15 gill-nets were set up for each occasion. Nets were left overnight (twenty-four hours period). Fish samples were collected the next day and transported to the laboratory in a cooler box with ice. Fish samples were measured and weighed in the laboratory. The standard length (cm) was recorded for individual fish sampled. Therefore, fish samples were weighed with an accuracy of ±0.001g using an analytical balance. Fish were identified to species following taxonomy key [11,26,29,36,37].

2.4 Data Analysis

Least squares regression analysis was used to calculate the length–weight relationship parameters [38] using SPSS 20.0 software. Only *Trichopodus trichopterus* and *Anabas testudineus* were used in this analysis. The *a* is the intercept, and *b* is the slope of the regression line by following in Equation 1, where W is the body weight (g), L is the total length (cm) [38]. In this study, however, standard length (cm) was used where tails were missing for most samples; therefore, total length was ignored in this analysis.

$$W = aL^b \quad (1)$$

The *b* is an exponent with a value nearly always between 2 and 4, often close to 3. The value of *b* equals 3 indicates that the fish grow symmetrically or isometrically. Values other than 3 indicate algometric growth: If *b*>3, the fish becomes heavier for its length as it grows larger. Logarithm was used to remove all outliers from the regression analyses as follows in Equation 2:

$$Log\ W = Log\ a + b\ Log\ L \quad (2)$$

Additionally, 95% confidence limits of *a* and *b* and the statistical significance level of r^2 (coefficient of determination) were estimated. Therefore, Fulton's condition factor (K) [39] was calculated using Equation 3 to compare dry and wet seasons for *Trichopodus trichopterus* and *Anabas testudineus* in the oil palm plantation. W = body weight (g), L = length of fish (cm), and 100 is a factor in bringing the value of K near unity.

$$K = \frac{100W}{L^3} \quad (3)$$

The condition factor (K) was used for comparing the condition, fatness, or well-being of fish in their habitat based on the assumption that heavier fish of a given length are in better condition [39]. Statistical analyses of one-way ANOVA with the post-hoc test were used for comparison between sites, the independent samples t-test was used to compare dry and wet seasons for 1) physicochemical water quality and 2) K values of *T. trichopterus* and *A. testudineus* in the oil palm plantation. Pearson correlation was used to determine correlations between water quality in each sampling drain. The statistical significance level was set at *p*=0.05.

3. Results and Discussion

3.1. Water Quality

The DOC ranges (Fig. 3a) at drainage with established palm trees area (i.e., 15-yo(A) 1^{st}G, 3-yo 2^{nd}G, and 9-yo 2^{nd}G) was much greater than at cleared-felled drain (CF 2^{nd}G). Hence, the DOC levels at CF 2^{nd}G was significantly lower than 9-yo 2^{nd}G ($p<0.05$). Widely range of observed DOC level in 15-yo(A) 1^{st}G, 3-yo 2^{nd}G, and 9-yo 2^{nd}G suggested that these plantation areas either have deeper peat or carbon leaching due to high supply of labile leaf litter produced by palm trees [40]. Furthermore, significantly lower DOC levels in CF 2^{nd}G than 9-yo 2^{nd}G could be explained by the following two possibilities. i) Peat subsidence has extensively occurred in CF 2^{nd}G resulting from the shallow peat in a block of plantation area, which is associated with the low DOC level in their drainage. ii) The 9-yo 2^{nd}G drain is located deep in the plantation, i.e., in the middle of peat dome, while CF 2^{nd}G is located at the edge of the peat dome. Therefore, DOC level was a wide range in the wet season than dry season (mean; 78.46±51.21mgL^{-1} and 46.67±47.06mgL^{-1}, respectively). This indicated that rainfall plays significant role in carbon runoff of organic soil from plantation blocks to the drainage system (Fig. 3a). Dissolved organic carbon plays a major role in the carbon cycles in an acidic condition of water bodies (peat swamp environment) which affects nutrient cycling also influences metal mobility and light penetration in aquatic habitats [41], [42].

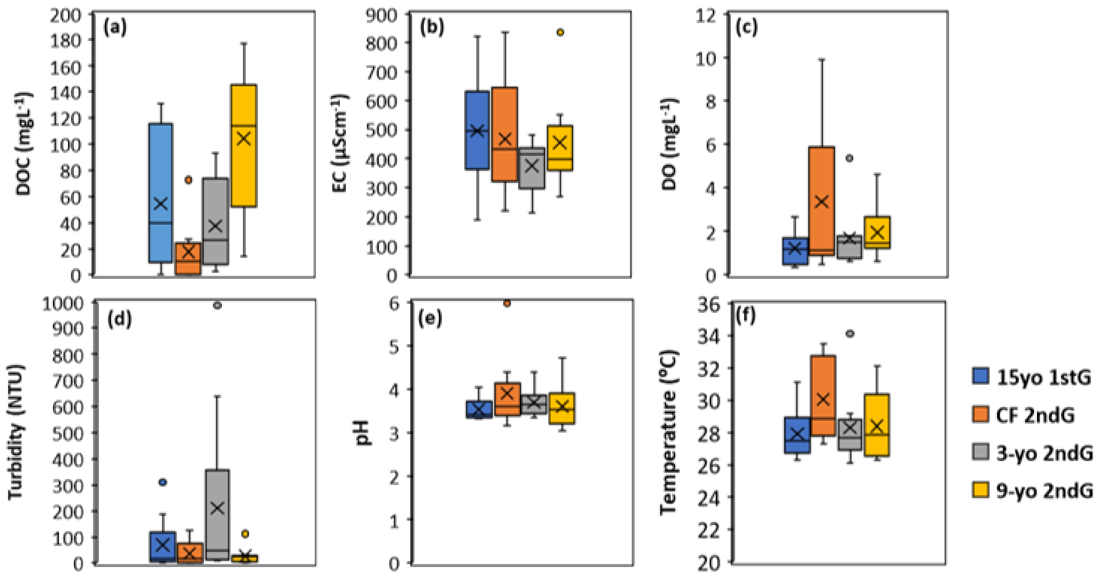

Fig. 3. Box and whiskers plot showing 25%, median, and 75% quartiles. **x** is the mean value, 95% confidence interval (whiskers), and outlier water quality; (a) DOC, (b) EC, (c) DO, (d) turbidity, (e)pH, and (f) temperature at the 15-years old of first-generation oil palm plantation (15-yo 1stG), cleared felled of second-generation oil palm plantation (CF 2ndG), 3-years old of second-generation oil palm plantation (3yo 2ndG) and 9-years old of second-generation oil palm plantation (9-yo 2ndG) at South Selangor, Malaysia. DOC: dissolved organic carbon, EC: electrical conductivity, and DO: dissolved oxygen

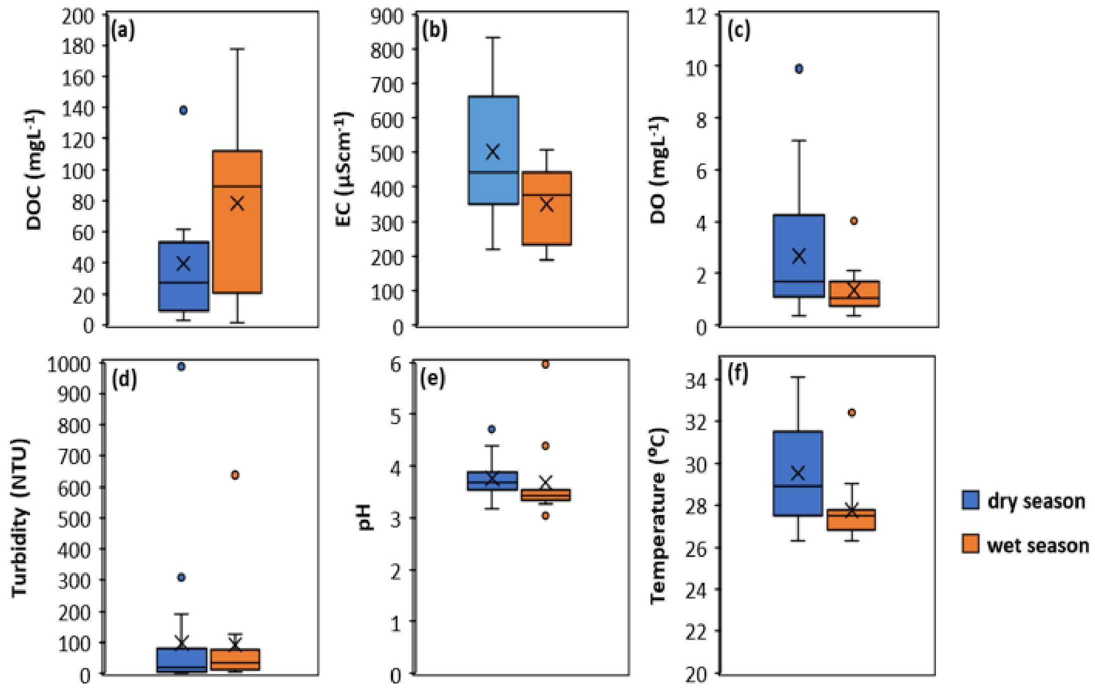

Fig. 4. Box and whiskers plot showing 25%, median, and 75% quartiles. **x** is the mean value, 95% confidence interval (whiskers), and outlier water quality; (a) DOC, (b) EC, (c) DO, (d) turbidity, (e)pH, and (f) temperature during dry and wet seasons in oil palm plantation at South Selangor, Malaysia. DOC: dissolved organic carbon, and EC: electrical conductivity

The EC range at the 15-yo(A) 1stG and CF 2ndG drains was much greater than at the 3-yo 2ndG and 9-yo 2ndG drains (Fig. 3b), whereas for seasonal comparison, the EC range in the dry season was much greater than in the wet season (Fig. 4b). Nevertheless, the differences were not significant either by sampling drainage drains or season (Fig. 3b and Fig. 4b). The level of EC can be used as a proxy to ionizable metals movement in the water body, which indicates the concentration of organic matter, nitrate, phosphate, and sulphate [43]. Shabalala *et al*., [44] reported that most studies resulted in high EC during the wet season, characterised by high surface runoff due to heavy rainfall. However, high EC observed during the dry season in this oil palm plantation could be due to the fertilizer deposition schedule to the oil palm trees. Applying fertilizer in the dry season maximizes the fertilizer efficiency, as in the wet season, it will wash out by rain. This could be explained due to the management's proposal and decision.

Our result shows no significant difference in DO level between sampling drains, although dissolved oxygen at CF 2ndG drain was widely ranged than the other drains (Fig. 3c). Furthermore, a widerange of turbidity levels was recorded at 3-yo 2ndG drain (Fig. 3d), whereas little difference in pH range between drains or seasons (Fig. 3e and Fig. 4e). The drainage temperature range was greater at CF 2ndG and 9-yo 2ndG drainage drains (Fig. 3f), whereas the temperature range in the dry season was larger than the wet season, as shown in Fig. 4f. The peat swamp area is known for low water pH values. Its water bodies have an extreme acidic environment, whiles pH and turbidity showed no significant changes between seasons could be because of the rain receiving for the whole year period.

3.2 Fish Distribution

Five species *Trichopodus trichopterus*, *Anabas testudineus*, *Channa striata*, *Clarias batracus*, and *Pristolepis grootii* were found in oil palm plantation (Fig. 5) and categorized as eurytopic species which are tolerable to slightly acidic or slightly alkaline [36]. The abundance of fish was higher in CF 2ndG followed by 9-yo 2ndG, 3-yo 2ndG, and 15-yo 1stG and 15-yo(R) 1stG, as shown in Fig. 5. The CF 2ndG drainage was wider and deeper than the other four drains, catching more fish. *Trichopodus trichopterus* was the most abundant fish in all drains in both seasons compared to other species (226 individuals). In contrast, *Anabas testudineus* was the second highest abundant fish (99 individuals), which were both species highly sampled at CF 2ndG drainage drain. A low number of *C. striata* and *C. batracus* were found (4 and 5 individuals, respectively), and only one individual of *P. grooti* was found at 15-yo(R) 1stG drainage in the dry season (Fig. 5). Generally, most fish caught in were relatively small and similar sized especially *T. trichopterus* and *A. testudineus* with the average length in all sampling drains being less than 14 cm. The average fish length was associated with the gill-net mesh size used (1 and 2 inches), defined as the target fish collected. Therefore, fish dispersal routes were influenced by local physical conditions, fish species, and size [45]. In terms of physical condition, low connection depths along the drainage system were a key factor in allowing small-bodied species to travel farther than large-bodied fish. This could be one of the reasons why *T. trichopterus* and *A. testudineus* were found in similar size between drains in oil palm plantations. However, variables in fish movement patterns are also based on ideal or preferable habitat selection. Usually, they will prefer the great food resource condition indicated by higher nutrient levels. Another study by Dosi *et al*., [46] found 13 species from the Tinbarap estate (oil palm), Sarawak, which included the five species in our study.

The total number of fish caught was highest in the dry season compared to the wet season with 184 and 152 individuals, respectively shown in Fig. 6. The high number of fish caught in the dry season was likely due to lower water levels and fish concentration in the drainage channels. The total number of *T. trichopteru*s collected was higher in the dry season than in the wet season, with 124 and 102 individuals, respectively. *Trichopodus trichopteru*s was the highest caught in the dry season in 9-yo 2ndG and CF 2ndG drainage with 38 and 66 individuals, respectively (Fig. 5). The number of *T. trichopteru*s was high during the wet season in the rest of sampling drains. Also, the total number of

A. testudineus caught was higher in the dry season than in the wet season, with 52 and 42 individuals, respectively. Several factors might be associated with a large number of fish caught in the dry season compared to the wet season sampling in this study. Reduction of water depth due to the management drainage blocking schedule and lack of sufficient rainfall resulted in larger fish population density allowed fishing gears and fishing methods were efficacious [47] for dry season sampling. Additionally, the passive sampling method, the gill net used, was associated with the low water depth and slow-flowing water bodies in oil palm drainage. Furthermore, the different number of fish caught between drains could be explained in this study due to fish specimens obtained from different depths and width of the drainage. Not surprisingly, the result showed that the number of fish was highest sampled in CF 1stG, which is a bigger and deeper drain than the smaller and shallower drain 15-yo(R) 1stG with the lowest number of fish collected. In another way, the drenched drainage for management purposes was noted in 15-yo(A) 1stG could be influenced by the lower number of fish collected in that drains even have similar width and depth to 3-yo 2ndG drainage.

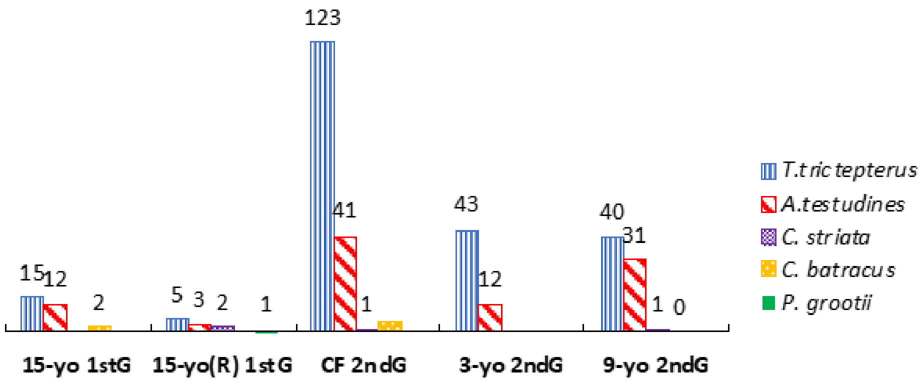

Fig. 5: Number of individual fish collected in oil palm plantation at South Selangor, Malaysia. 15-yo 1stG: 15 years old of first generation oil palm plantation, 15-yo(R) 1stG: 15 years old (railway) of first generation oil palm plantation, CF 2ndG: cleared-felled of second generation oil palm plantation, 3-yo 2ndG: 3 years old of second generation oil palm plantation and 9-yo 2ndG: 9 years old of second generation oil palm plantation

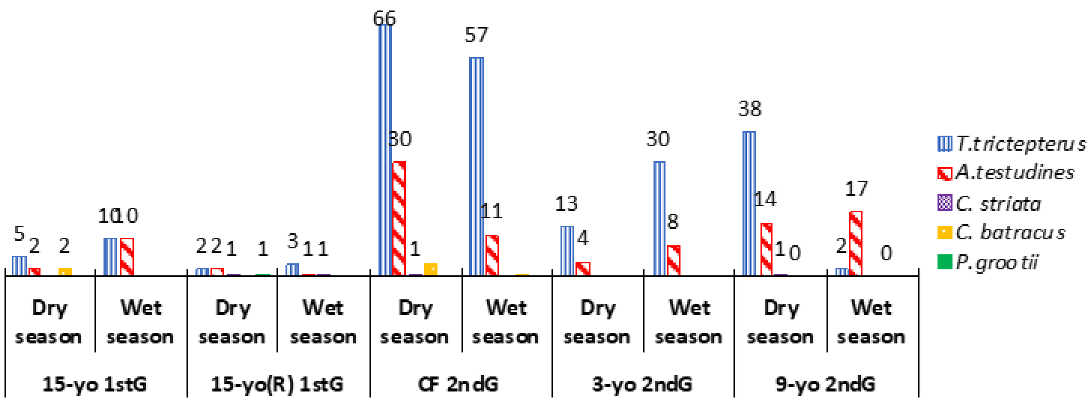

Fig. 6 Number of individual fish collected during dry and wet season in oil palm plantation at South Selangor, Malaysia. 15-yo 1stG: 15 years old of first-generation oil palm plantation, 15-yo(R) 1stG: 15 years old (railway) of first-generation oil palm plantation, CF 2ndG: cleared-felled of second-generation oil palm plantation, 3-yo 2ndG: 3 years old of second-generation oil palm plantation and 9-yo 2ndG: 9 years old of second-generation oil palm plantation

The dominance of some species is a dynamic process with temporal variations of biotic and abiotic conditions leading to other species becoming dominant, allowing the species with similar ecological requirements to coexist [48]. For example, among the recorded fish species in an oil palm plantation, the most abundant and available fish species in an oil palm plantation are *T. trichopterus* and *A. testudineus* (Fig. 5). Both *T. trichopterus* and *A. testudineus* were omnivores' diet species that feed on macrophytic vegetation, fish fry, zooplankton, shrimps, crustaceans, and insect larvae [49]. Furthermore, Chua *et al.*, [50] discovered that fish species associated with oil palm had superior mouthparts, which was significantly linked to a preference for feeding on fallen terrestrial invertebrates at/near the water surface. The high presence of *T. trichopterus* and *A. testudineus* (surface feeders) might linked to the dominance of grasses along oil palm drainage's degraded riparian zones. The sampling method (gill net) used in this study which targeted to middle and near to the surface of water column species, could be one of the reasons for less number of *C. striata*, *C. batracus* as they were bottom feeder species [47,51]. Furthermore, *Channa striata*, *C. batracus* was collected in this study because they ate the dead fish clogged in the gill nets, especially *T. trichopterus* and *A. testudineus* as noted that they were the carnivores diet species [52].

Trichopodus trichopterus is a most common air-breathing freshwater fish occupied with a fixture breathing organ called the labyrinth [52], [53] that generally populates in the stagnant water body with high aquatic vegetation. *Trichopodus trichopterus* is considered a strong and highly adaptive species that vary broadly in water quality parameters [54]. Other studies [55-58] stated that *T. trichopterus* were found in water with EC ranges from 22 µS up to 718 µS, DO below 3.0 mgL^{-1}, and pH values lower than 3.5 having similar conditions to this study. It has been reported that *T. trichopterus* are found in marshes, lakes, swamps ponds, rice fields, drainage canals, and rivers of Southeast Asia [47,51].

Furthermore, Syarifuddin and Kramer [55] suggested the number of individuals *T. trichopterus* present are influenced the forming of feeding aggregations for short-term temporal patterns of resource availability. Those explained by the highest number of *T. trichopterus* caught compared to other species in the plantation in broad sampling. Additionally, the other possible reason for the highest number of *T. trichopterus* could be the aggregations' behavior of male fish in the preparation of nesting area for the female to breed[55]. Supported by Pollak et al. [56], they reported *T. trichopterus* have multiple matings, and the females spawning several times through the year, resulting in no seasonality breeding for this species. Furthermore, matured length of *T. trichopterus* for mating and breeding is about 7cm [38] associated with the average length of *T. trichopterus* in this study. However, no separated sexuality has been done in this study which could be limited information to support that idea.

Similar to *T. trichopterus, A. testudineus* also occupy with fixture breathing organ called the labyrinth [52], [59], [60] having the ability to take the oxygen from the air and also have extraordinary tolerate to unfavourable water conditions, which generally associated with turbid stagnant waters. Also, this study found a lower number of *A. testudineus*, i.e., insectivore-omnivore dieter [20], than *T. trichopterus,* which may be related to a lack of insects in the oil palm plantation due to heavy pesticide applications.

3.3 Condition of *T. trichopterus* and *A. testudineus*

Length-weight relationship (LWR) in 'Cube Law' is used to estimate the weight corresponding to a given length. Condition factors (K) are used for comparing the condition of fish: 'fatness' or 'well-being' based on the assumption that heavier fish of a given length are in better condition [38,39]. The relationship between length and weight differs among fish species according to their inherited body shape and species according to the fish condition. The condition could reflect food availability and growth. Froese *et al*., [38] reported that 82% of the variance in a plot of log *a* over *b* in LWR can be explained by allometric versus isometric growth patterns and different body shapes of the respective species. The LWR is useful for measuring changes in the population health, determining the relative condition of small fish compared to large fish (from the slope of the regression), and comparing the population condition to the state-wide standards deliberated [38].

In this study, two abundance species (*T. trichopterus* and *A. testudineus*) in oil palm plantations were used in the regression analysis for the LWR (Table 2 and Table 3). The differences in the slope (*b*-values) in length-weight regressions can be attributed to the combination of one or more factors, including habitat preferable, area, seasonal effect, a degree of stomach fullness (fatness), gonad maturity, sexuality, biological condition, geographical, temporal, environmental conditions and sampling factors such as preservation technique [23,38,61,62]. Furthermore, growth is said to be positive allometric when the weight of an organism increases more than the length ($b>3$) and negative allometric when length increases more than weight ($b<3$) [63]. Hence, the *b*-values of LWR that close to 3 indicate isometric growth and represent the ideal shape of fish.

The *b*-values of *T. trichopterus* in all sampling drains were lower than 2 except for 9-yo 2ndG drain (2.14) (Table 2). Also, the *b*-values of *T. trichopterus* for dry and wet seasons were lower than an ideal isometric value (Table 3) and not within the range reported by Froese *et al.,* [38]. This condition indicates that *T. trichopterus* have a slower growth rate, which they become slender as the length increases [64]. Therefore, our result shows that sampling drains and seasons did not affect the *T. trichopterus* in oil palm plantations. On the other hand, the *b*-values of *A. testudineus* in all sampling drains were more than 2 except for 9-yo 2ndG drain and two sampling drains (CF 2ndG and 3-yo 2ndG) recorded b-values near to the isometric growth value (Table 2). Furthermore, their *b*-values for both seasons was within the typical ideal *b*-values (2.5 to 3.5 [38]) (Table 3). Our result showed that this species was in a desirable growth rate and demonstrated they were doing better compared to *T. trichopterus* in the oil palm plantation system [38,63,65]. The *A. testudineus* have a great tolerance to the high DOC, providing a more favourable environment in oil palm plantations [66]. Furthermore, the coefficient of determination (r^2) values explained the proper fit of the model for growth [67], which *A. testudineus* presented a high coefficient of determination (r^2) compared to *T. trichopterus* revealing their good fitness (Table 2 and Table 3).

The relationship of length-weight can be used in the estimation of condition factor (K) of fish species in assessing the well-being of fish [62,68,69]. The value of K is calculated from the weight and length and can be used to estimate changes in nutritional condition [68]. Since K value is a measurement relating to the length and the weight, it could influence the same factors as LWR, such as sexuality, seasonality, fish age, maturation stage, gut fullness, food type consumed, fat quantity reserved, and muscular development degree [38]. Abowei [70] reported that K values of different populations of the same species indicate food resources and period of breeding. According to Gupta *et al*., [38], the difference in condition factors could be due to food availability at a particular time, strongly correlated to the fish size classes and their relative fitness, which could be linked to varying water qualities representing the habitat preferences. The weight of fish increased as they utilized the food items available for growth and energy [71].

Both *T. trichopterus* and *A. testudineus* were considered in good condition during both seasons as their K values were more than 1 (Table 5) [38,62]. Those results also refer to higher food resources in oil palm plantations and become a preferable habitat to them. Crops cultivation showed an excess of the nutrients applied to water systems have been reported widely [72,73]. The excess nutrients either remain in the soil or are lost through erosion or leaching, diluting in runoff water into the drainage.

Table 2
Descriptive statistics on the length and weight measurements, sample sizes (n), regression parameters *a* and *b* of the length-weight relationship (LWR), and their 95% confidence limits and coefficients of determination (r^2) of *T. trichopterus* and *A. testudineus* at each sampling drains in oil palm plantation, South Selangor, Malaysia.

Species	Sites	n	Length (cm)		Body Weight (g)		Regression parameter		95% CL of *a*	95% CL of *b*	r^2
			Min	Max	Min	Max	*a*	*b*			
T. trichtopterus	15-yo 1stG	12	5.1	7.0	4.04	8.24	0.813	1.11	0.036-1.812	0.623-2.836	0.17
	15-yo(R) 1stG	5	6.8	7.8	4.85	8.56	0.111	1.99	0.000-2.556	5.384-9.379	0.20
	CF 2ndG	91	4.8	8.1	3.13	12.03	0.188	1.87	0.083-0.426	1.413-2.324	0.43
	3-yo 2ndG	34	4.5	6.3	3.19	7.08	0.401	1.45	0.019-1.768	0.571-2.322	0.26
	9-yo 2ndG	24	5.5	7.3	3.53	8.63	0.106	2.14	0.028-0.399	1.407-2.872	0.63
A. testudineus	15-yo 1stG	10	5.1	13.4	5.96	82.81	0.231	2.00	0.001-3.862	0.562-3.346	0.57
	15-yo(R) 1stG	not enough data									
	CF 2ndG	38	5.1	14.5	3.35	83.92	0.034	2.92	0.021-0.057	2.656-3.184	0.93
	3-yo 2ndG	12	5.2	13.5	4.81	84.90	0.036	2.95	0.014-0.090	2.420-3.405	0.95
	9-yo 2ndG	30	4.9	7.4	4.17	11.94	0.303	1.94	0.113-0.811	1.195-2.293	0.60

Note: 15-yo 1stG: 15 years old of first-generation oil palm plantation, 15-yo(R) 1stG: 15 years old (railway) of first-generation oil palm plantation, CF 2ndG: cleared-felled of second-generation oil palm plantation, 3-yo 2ndG: 3 years old of second-generation oil palm plantation and 9-yo 2ndG: 9 years old of second-generation oil palm plantation.

Table 3
Descriptive statistics on the length and weight measurements, sample sizes (n), regression parameters *a* and *b* of the length-weight relationship (LWR), and their 95% confidence limits and coefficients of determination (r^2) of overall *T. trichopterus* and *A. testudineus* in dry and wet seasons in oil palm plantation, South Selangor, Malaysia.

Species	Sites	n	Length (cm)		Body Weight (g)		Regression parameter		95% CL of *a*	95% CL of *b*	r^2
			Min	Max	Min	Max	*a*	*b*			
T. trichopterus	Dry	89	5.2	7.8	3.13	12.03	0.064	2.39	0.034-0.123	2.034-2.750	0.67
	Wet	77	4.5	8.1	3.19	11.84	0.398	1.52	0.216-0.733	1.173-1.870	0.50
A. testudineus	Dry	45	5.1	14.5	3.35	83.92	0.034	2.89	0.021-0.056	2.639-3.146	0.92
	Wet	46	4.9	13.5	4.17	84.90	0.040	2.93	0.028-0.059	2.725-3.128	0.95

The excessive nutrient levels in the oil palm drainage verified that primary production could produce high macrophytic vegetation and zooplankton as food resources for both *T. trichopterus* and *A. testudineus.* Furthermore, the K values for both *T. trichopterus* and *A. testudineus* were significantly higher in the wet season, showing seasonality variable that may occur (Table 5) [38]. The possibility that both species were in a better proportion 'fatter' during the wet season could be explained by migration activities from the adjacent Kuala Langat swamp to an oil palm plantation, which act as a flood plain due to breading season. An oil palm plantation, which is high in nutrient levels, is preferable for breading [34,74].

Table 4
Condition factor (K) of *T. trichtopterus* and *A. testudineus* between drains at oil palm plantation.

Species	15-yo 1stG	15-yo(R) 1stG	CF 2ndG	3-yo 2ndG	9-yo 2ndG
T. trichtopterus	2.85±0.99	1.61±0.35	2.57±0.62	2.97±0.68	2.25±0.29
A. testudineus	3.72±0.81		3.00±0.66	3.31±0.48	3.27±0.65

15-yo 1stG: 15 years old of first-generation oil palm plantation, 15-yo(R) 1stG: 15 years old (railway) of first-generation oil palm plantation, CF 2ndG: cleared-felled of second-generation oil palm plantation, 3-yo 2ndG: 3 years old of second-generation oil palm plantation and 9-yo 2ndG: 9 years old of second-generation oil palm plantation.

Table 5
Condition factor (K) of *T. trichtopterus* and *A. testudineus* between seasons at oil palm plantation.

	Wet season	Dry season
T. trichtopterus	3.08±0.67[a]	2.19±0.37[b]
A. testudineus	3.58±0.59[a]	2.83±0.41[b]

Different letters represent significant different ($p<0.05$).

4. Conclusions

Five eurytopic species (tolerable to slightly acidic or slightly alkaline) were found in oil palm plantation with *T. trichopterus* and *A. testudineus* were the two abundant species. The *A. testudineus* showed highly adaption with high DOC level's drainage, whilst *T. trichopterus* have not affected by water quality changes. Fish's fatness (i.e., a proxy of well-being and growth form) in the oil palm drainage system reflects food availability and growth linked to environmental factors. It is argued that the fatness of fish implies excessive nutrient levels is occurring at the oil palm plantation. The length-weight relationship regression showed that *A. testudineus* was in a desirable growth rate and demonstrated they were doing better compared to *T. trichopterus* in the oil palm plantation system. The condition factors of both species showed that they were fatter in the wet season than dry season could be explained due to migration activities from the adjacent Kuala Langat swamp to the high productivity (i.e. high nutrient level) drainage system of oil palm plantation.

Conversion of the peat swamp forest system to oil palm plantations has significantly affected the water quality and habitat alteration. A drainage system constructed in oil palm plantations has increased EC and pH levels (becoming slightly less acidic). Further research into the direct and indirect effects of oil palm management practices on fish is needed to provide a more detailed understanding of how fish can be used to monitor and improve water management in the oil palm drainage system (i.e., heavy metal in fish and drainage). The basic information obtained from the study will help undertake the development and management of water systems. In addition, it may serve to encourage further study on aquatic diversity in the water body system.

Author Contributions

Fieldwork, Formal Analysis, Writing-Original draft preparation: S.N.F.A.; Laboratory Analysis: S.N.F.A. and M. N. H., Supervision, Writing-Review and Editing, R.P., S. E, K.N and H.H. All authors have read and approved the final manuscript.

Acknowledgement

The authors gratefully acknowledge MAAH Sdn. Bhd., especially to Mrs. Kamsiah and late Mr. Nizam for granting site access (oil palm plantation). We acknowledge the editors and two anonymous reviewers for their constructive comments and suggestions that have helped to improve the quality of this paper.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] S. Villéger, S. Brosse, M. Mouchet, D. Mouillot, and M. J. Vanni, “Functional ecology of fish: current approaches and future challenges,” *Aquatic Sciences*, vol. 79, no. 4, pp. 783–801, 2017, doi: 10.1007/s00027-017-0546-z.

[2] Y. Nurulita, E. M. Adetutu, K. K. Kadali, D. Zul, A. A. Mansur, and A. S. Ball, “The assessment of the impact of oil palm and rubber plantations on the biotic and abiotic properties of tropical peat swamp soil in Indonesia,” *International Journal of Agricultural Sustainability*, vol. 13, no. 2, pp. 150–166, Apr. 2015, doi: 10.1080/14735903.2014.986321.

[3] A. Maceda-Veiga, A. J. Green, and A. de Sostoa, “Scaled body-mass index shows how habitat quality influences the condition of four fish taxa in north-eastern Spain and provides a novel indicator of ecosystem health,” *Freshwater Biology*, vol. 59, no. 6, pp. 1145–1160, Jun. 2014, doi: https://doi.org/10.1111/fwb.12336.

[4] S. L. Johnson and N. H. Ringler, “The response of fish and macroinvertebrate assemblages to multiple stressors: A comparative analysis of aquatic communities in a perturbed watershed (Onondaga Lake, NY),” *Ecological Indicators*, vol. 41, pp. 198–208, 2014, doi: https://doi.org/10.1016/j.ecolind.2014.02.006.

[5] U. Silins *et al.*, “Five-year legacy of wildfire and salvage logging impacts on nutrient runoff and aquatic plant, invertebrate, and fish productivity,” *Ecohydrology*, vol. 7, no. 6, pp. 1508–1523, Dec. 2014, doi: https://doi.org/10.1002/eco.1474.

[6] C. Lévêque, T. Oberdorff, D. Paugy, M. L. J. Stiassny, and P. A. Tedesco, “Global diversity of fish (Pisces) in freshwater,” *Hydrobiologia*, vol. 595, no. 1, pp. 545–567, 2008, doi: 10.1007/s10750-007-9034-0.

[7] A. E. Deacon, H. Shimadzu, M. Dornelas, I. W. Ramnarine, and A. E. Magurran, “From species to communities: The signature of recreational use on a tropical river ecosystem,” *Ecology and Evolution*, vol. 5, no. 23, pp. 5561–5572, 2015, doi: 10.1002/ece3.1800.

[8] J. H. M. Wösten, E. Clymans, S. E. Page, J. O. Rieley, and S. H. Limin, “Peat–water interrelationships in a tropical peatland ecosystem in Southeast Asia,” *Catena*, vol. 73, no. 2, pp. 212–224, Apr. 2008, doi: 10.1016/j.catena.2007.07.010.

[9] D. H. Janzen, “Tropical Blackwater Rivers, Animals, and Mast Fruiting by the Dipterocarpaceae,” *Biotropica*, vol. 6, no. 2, pp. 69–103, Nov. 1974, doi: 10.2307/2989823.

[10] C. M. Yule, “Loss of biodiversity and ecosystem functioning in Indo-Malayan peat swamp forests,” *Biodiversity and Conservation*, vol. 19, no. 2, pp. 393–409, 2010, doi: 10.1007/s10531-008-9510-5.

[11] F. W. H. Beamish, R. B. Beamish, and S. L.-H. Lim, “Fish Assemblages and Habitat in a Malaysian Blackwater Peat Swamp,” *Environmental Biology of Fishes*, vol. 68, no. 1, pp. 1–13, 2003, doi: 10.1023/A:1026004315978.

[12] K. Martin-Smith, “Biodiversity patterns of tropical freshwater fish following selective timber extraction: A case study from Sabah, Malaysia,” *Italian Journal of Zoology*, vol. 65, no. sup1, pp. 363–368, Jan. 1998, doi: 10.1080/11250009809386847.

[13] D. Coates, O. Poeu, U. Suntornratana, N. Thanh Tung, and S. Viravong, “Biodiversity and fisheries in the Lower Mekong Basin. Mekong Development Series No. 2,” *Mekong River Commission, Phnom Penh*, no. 2, pp. 1–30pp, 2003.

[14] M. R. Y. Zainudin, “Assessment of Fish Community Distribution and Composition in The Perak River n order to Determine Biological Indicators” Thesis: Master of Science January 2005, no. January, pp. 1–38, 2005.

[15] M. Kottelat and E. Widjanarti, “The fishes of Danau Sentarum National Park and the Kapuas Lakes Area, Kalimantan Barat, Indonesia,” *Raffles Bulletin of Zoology*, vol. 13, no. 13, pp. 139–173, 2005.

[16] K. A. A. Rahim, S. K. Daud, S. S. Siraj, A. Arshad, Y. Esa, and E. R. Ibrahim, “Freshwater fish diversity and composition in Batang Kerang floodplain, Balai Ringin, Sarawak,” *Pertanika Journal of Tropical Agricultural Science*, vol. 32, no. 1, pp. 7–16, 2009.

[17] M. F. Ahmad and A. Samat, “Species Composition and Abundance of Peat Swamp Fishes in Selected Areas of Selangor, Malaysia,” vol. 44, pp. 139–145, 2015.

[18] J. H. M. Wösten, A. B. Ismail, and A. L. M. van Wijk, “Peat subsidence and its practical implications: a case study in Malaysia,” *Geoderma*, vol. 78, no. 1, pp. 25–36, 1997, doi: https://doi.org/10.1016/S0016-7061(97)00013-X.

[19] M. Barthel *et al.*, “Written by Study on the environmental impact of palm oil consumption and on existing sustainability standards Final Report and Appendices,” 2018.

[20] “MPOC – Malaysian Palm Oil Council.” https://mpoc.org.my/ (accessed Oct. 13, 2020).

[21] M. R. da Costa, T. M. Mattos, J. L. Borges, and F. G. Araújo, “Habitat preferences of common native fishes in a tropical river in southeastern Brazil,” *Neotropical Ichthyology*, vol. 11, no. 4, pp. 871–880, 2013, doi: 10.1590/S1679-62252013000400015.

[22] M. Inoue and S. Nakano, “Fish abundance and habitat relationships in forest and grassland streams, northern Hokkaido, Japan,” *Ecological Research*, vol. 16, no. 2, pp. 233–247, Jun. 2001, doi: https://doi.org/10.1046/j.1440-1703.2001.00389.x.

[23] M. S. Hossain, N. Gopal Das, S. Sarker, and M. Z. Rahaman, “Fish diversity and habitat relationship with environmental variables at Meghna river estuary, Bangladesh,” *Egyptian Journal of Aquatic Research*, vol. 38, no. 3, pp. 213–226, 2012, doi: 10.1016/j.ejar.2012.12.006.

[24] R. Zakaria, M. Mansor, and A. B. Ali, “Swamp-riverine tropical fish population: a comparative study of two spatially isolated freshwater ecosystems in Peninsular Malaysia,” *Wetlands Ecology and Management*, vol. 6, no. 4, pp. 261–268, 1998, doi: 10.1023/A:1008436005627.

[25] B. Velmurugan, M. Selvanayagam, E. I. Cengiz, and P. Ugurlu, “Scanning electron microscopy study of the gills , scales and erythrocytes of *Anabas testudineus* upon exposure to chlorpyrifos,” vol. 2248, no. December, 2015, doi: 10.1080/02772248.2015.1041527.

[26] C. K. C. Ng, T. Y. Lim, A. Ahmad, and M. Z. Khaironizam, “Provisional checklist of freshwater fish diversity and distribution in Perak, Malaysia, and some latest taxonomic concerns,” *Zootaxa*, vol. 4567, no. 3, pp. 515–545, Mar. 2019, doi: 10.11646/zootaxa.4567.3.5.

[27] N. C. Keat-Chuan and O. P. Aun-Chuan, “An overview of the status, trends and challenges of freshwater fish research and conservation in Malaysia.” [Online]. Available: http://ffish.asia/

[28] A. Izzati and S. Abdullah, “Diversity and distribution of stream fishes of Pulau Langkawi, Malaysia,” *Sains Malaysiana*, vol. 39, no. 6, pp. 869–875, 2010, [Online]. Available: http://pkukmweb.ukm.my/jsm/malay_journals/jilid39bil6_2010/Jilid39Bil6_2010ms869-875.html

[29] Mohd. Azmi Ambak. and Penerbit Universiti Malaysia Terengganu., “Fishes of Malaysia,” p. 334, 2010.

[30] a S. R. M. Shah, H. H. Zarul, K. Y. Chan, R. Zakaria, K. H. Khoo, and Mashhor Mansor, "A recent survey of freshwater fishes of the Paya Beriah peat swamp forest, North Perak, Malaysia," *Journal of Biosciences*, vol. 17, no. 1, pp. 51–64, 2006.

[31] R. H. Lowe-Mcconnel, "Fish communities in tropical freshwaters: their distribution, ecology and evolution. New York: Logman." Inc, 1975.

[32] D. S. Johnson, "Distributional Patterns of Malayan Freshwater Fish," *Ecology*, vol. 48, no. 5, pp. 722–730, Nov. 1967, doi: 10.2307/1933729.

[33] H. A. Sule, A. Ismail, M. N. Azmai Amal, S. Z. Zulkifli, M. F. A. Mohd Roseli, and S. Shohaimi, "Water quality influences on fish occurrence in peat swamp forest and its converted areas in North Selangor, Malaysia," *Sains Malaysiana*, vol. 47, no. 11, pp. 2589–2600, 2018, doi: 10.17576/jsm-2018-4711-01.

[34] X. Giam *et al.*, "Mitigating the impact of oil-palm monoculture on freshwater fishes in Southeast Asia," *Conservation Biology*, vol. 29, no. 5, pp. 1357–1367, Oct. 2015, doi: 10.1111/cobi.12483.

[35] A. E. Deacon, H. Shimadzu, M. Dornelas, I. W. Ramnarine, and A. E. Magurran, "From species to communities: The signature of recreational use on a tropical river ecosystem," *Ecology and Evolution*, vol. 5, no. 23, pp. 5561–5572, 2015, doi: 10.1002/ece3.1800.

[36] P. K. L. Ng, J. B. Tay, and K. K. P. Lim, "Diversity and conservation of blackwater fishes in Peninsular Malaysia, particularly in the North Selangor peat swamp forest," *Hydrobiologia*, vol. 285, no. 1, pp. 203–218, 1994, doi: 10.1007/BF00005667.

[37] P. G. Lee and P. K. L. Ng, "The systematics and ecology of snakeheads (Pisces: Channidae) in Peninsular Malaysia and Singapore," *Hydrobiologia*, vol. 285, no. 1–3, pp. 59–74, Jun. 1994, doi: 10.1007/BF00005654.

[38] R. Froese, J. T. Thorson, and R. B. Reyes Jr, "A Bayesian approach for estimating length-weight relationships in fishes," *Journal of Applied Ichthyology*, vol. 30, no. 1, pp. 78–85, Feb. 2014, doi: https://doi.org/10.1111/jai.12299.

[39] R. D. M. Nash, A. H. Valencia, and A. J. Geffen, "The origin of Fulton's condition factor - Setting the record straight," *Fisheries*, vol. 31, no. 5, pp. 236–238, 2006.

[40] T. Rixen, A. Baum, F. Wit, and J. Samiaji, "Carbon leaching from tropical peat soils and consequences for carbon balances," *Frontiers in Earth Science*, vol. 4, Jul. 2016, doi: 10.3389/feart.2016.00074.

[41] C. E. W. Steinberg, "Ecology of Humic Substances in Freshwaters," *Ecology of Humic Substances in Freshwaters*, 2003, doi: 10.1007/978-3-662-06815-1.

[42] S. Strohmeier *et al.*, "Concentrations and fluxes of dissolved organic carbon in runoff from a forested catchment: Insights from high frequency measurements," *Biogeosciences*, vol. 10, no. 2, pp. 905–916, 2013, doi: 10.5194/bg-10-905-2013.

[43] V. Balaram, "Rare earth elements: A review of applications, occurrence, exploration, analysis, recycling, and environmental impact," *Geoscience Frontiers*, vol. 10, no. 4, pp. 1285–1303, 2019, doi: https://doi.org/10.1016/j.gsf.2018.12.005.

[44] A. N. Shabalala, L. Combrinck, and R. McCrindle, "Effect of farming activities on seasonal variation of water quality of Bonsma Dam, KwaZulu-Natal," *South African Journal of Science*, vol. 109, no. 7–8, pp. 1–7, 2013, doi: 10.1590/sajs.2013/20120052.

[45] E. Hohausová, R. J. Lavoy, and M. S. Allen, "Fish dispersal in a seasonal wetland: Influence of anthropogenic structures," *Marine and Freshwater Research*, vol. 61, no. 6, pp. 682–694, 2010, doi: 10.1071/MF09140.

[46] E. Michael Dosi, A. Alek Tuen, I. Chiron Yaman, and K. Lip Khoon, "Fishes of a Conserved Peat Swamp Forest in an Oil Palm Plantation," *Oil palm Bulletin: Malaysian Palm Oil Board*, p. pp:1-5.

[47] S. M. Galib, S. M. A. Naser, A. B. M. Mohsin, N. Chaki, and F. H. Fahad, "Fish diversity of the River Choto Jamuna, Bangladesh: Present status and conservation needs," *International Journal of Biodiversity and Conservation*, vol. 5, no. 6, pp. 389–395, 2013, doi: 10.5897/IJBC2013.0552.

[48] E. Lo and P. Trujillo-jime, "Patterns in the distribution of fish assemblages in Rio Amacuzac , Mexico: influence of abiotic factors and biotic factors," pp. 457–469, 2010, doi: 10.1007/s11160-009-9153-y.

[49] C. Sokheng *et al.*, "Fish migrations and spawning habits in the Mekong mainstream: a survey using local knowledge (basin-wide)," *Assessment of Mekong fisheries: Fish Migrations and spawning and the Impact of water Management Project (AMFC). AMFP Report*, vol. 2, p. 99, 1999.

[50] K. W. J. Chua, F. K. S. Lim, A. B. Ahmad, H. H. Tan, and D. C. J. Yeo, "Morphological traits mediate fish occurrences in oil palm-impacted tropical streams," *Freshwater Biology*, vol. 65, no. 6, pp. 1153–1164, Jun. 2020, doi: https://doi.org/10.1111/fwb.13500.

[51] R. M. Kobza, J. C. Trexler, W. F. Loftus, and S. A. Perry, "Community structure of fishes inhabiting aquatic refuges in a threatened Karst wetland and its implications for ecosystem management," *Biological Conservation*, vol. 116, no. 2, pp. 153–165, 2004, doi: https://doi.org/10.1016/S0006-3207(03)00186-1.

[52] M. Kottelat and W. H. T. of Sri Lanka, *Fishes of Laos*. Colombo Sri Lanka: WHT Publications, 2001. Accessed: Nov. 10, 2021.

[53] W. Rainboth, "Inland fishes of India and adjacent countries," *Reviews in Fish Biology and Fisheries*, vol. 4, no. 1, pp. 135–136, 1994, doi: 10.1007/BF00043269.

[54] T. Surasinghe, R. Kariyawasam, H. Sudasinghe, and S. Karunarathna, "Challenges in Biodiversity Conservation in a Highly Modified Tropical River Basin in Sri Lanka," *Water* , vol. 12, no. 1. 2020. doi: 10.3390/w12010026.

[55] S. Syarifuddin and D. L. Kramer, "The effect of group size on space use and aggression at a concentrated food source in blue gouramis, *Trichogaster trichopterus* (Pisces: Belontiidae)," *Environmental Biology of Fishes*, vol. 46, no. 3, pp. 289–296, 1996, doi: 10.1007/BF00005005.

[56] E. I. Pollak, T. Thompson, A. L. Stabler, and D. Keener, "Multiple matings in the blue gourami, *Trichogaster trichopterus* (Pisces, Belontiidae)," *Animal Behaviour*, vol. 29, no. 1, pp. 55–63, 1981, doi: 10.1016/S0003-3472(81)80151-0.

[57] M. N. Amal Azmai *et al.*, "Fishes of North Selangor Peat Swamp Forest," 2020, Accessed: Nov. 10, 2021. [Online]. Available: https://www.mybis.gov.my/pb/3543

[58] K. Yuen. Lee Universiti Malaya., Institut Sains Biologi., "Fish community of the North Selangor peat swamp forest," 2003.

[59] G. M. Hughes, S. C. Dube, and J. S. D. Munshi, "Surface area of the respiratory organs of the Climbing perch, *Anabas testudineus* (Pisces: Anabantidae)," *Journal of Zoology*, vol. 170, no. 2, pp. 227–243, Jun. 1973, doi: https://doi.org/10.1111/j.1469-7998.1973.tb01376.x.

[60] B. Velmurugan, M. Selvanayagam, E. I. Cengiz, and P. Ugurlu, "Scanning electron microscopy study of the gills, scales and erythrocytes of *Anabas testudineus* upon exposure to chlorpyrifos," *Toxicological & Environmental Chemistry*, vol. 97, no. 2, pp. 208–220, Feb. 2015, doi: 10.1080/02772248.2015.1041527.

[61] O. Özaydın, D. Uçkun, S. Akalın, S. Leblebici, and Z. Tosunoğlu, "Length–weight relationships of fishes captured from Izmir Bay, Central Aegean Sea," *Journal of Applied Ichthyology*, vol. 23, no. 6, pp. 695–696, Dec. 2007, doi: https://doi.org/10.1111/j.1439-0426.2007.00853.x.

[62] U. K. Sarkar *et al.*, "Length weight relationship and condition factor of selected freshwater fish species found in River Ganga, Gomti and Rapti, India," *Journal of Environmental Biology*, vol. 34, no. 5, pp. 951–956, 2013.

[63] K. Kumar, P. L. Lalrinsanga, M. Sahoo, U. L. Mohanty, R. Kumar, and A. K. Sahu, "Length-weight Relationship and Condition Factor of *Anabas testudineus* and *Channa* Species under Different Culture Systems," vol. 5, no. 1, pp. 74–78, 2013, doi: 10.5829/idosi.wjfms.2013.05.01.64201.

[64] M. M. Isa, C. S. Rawi, R. Rosla, S. Anuar, and M. Shah, "Length – weight Relationships of Freshwater Fish Species in Kerian River Basin and Pedu Lake," *Research Journal of Fisheries and Hydrobiology*, vol. 5, no. 1, pp. 1–8, 2010.

[65] Mr. Pervin and M. Golam Mortuza, "Notes on Length-Weight Relationship and Condition Factor of Fresh Water Fish, Labeo boga (Hamilton) (*Cypriniformes: Cyprinidae*)," *Rajshahi University Journal of Zoology*, vol. 27, pp. 97–98, 2008, [Online]. Available: http://journals.sfu.ca/bd/index.php/UJZRU

[66] B. Y. G. M. Hughes and B. N. Singh, "Respiration in an Air-Breathing Fish, Bloch," pp. 265–280, 1970.

[67] J. Brodziak, "Fitting length-weight relationships with linear regression using the log-transformed allometric model with bias-correction," *H-12-03*, no. August, p. 4, 2012.

[68] B. K. Gupta, U. K. Sarkar, S. K. Bhardwaj, and A. Pal, "Condition factor, length–weight and length–length relationships of an endangered fish Ompok pabda (Hamilton 1822) (*Siluriformes: Siluridae*) from the River Gomti, a tributary of the River Ganga, India," *Journal of Applied Ichthyology*, vol. 27, no. 3, pp. 962–964, Jun. 2011, doi: https://doi.org/10.1111/j.1439-0426.2010.01625.x.

[69] P. K. A. Sekitar, M. Hamid, M. Mansor, and S. A. M. Nor, "Length-weight relationship and condition factor of fish populations in Temengor Reservoir: Indication of environmental health," *Sains Malaysiana*, vol. 44, no. 1, pp. 61–66, 2015.

[70] J. F. N. Abowei, "The Condition Factor, Length-Weight Relationship and Abundance of *Ilisha africana* (Block, 1795) from Nkoro River Niger Delta, Nigeria," *Advance Journal of Food Science and Technology*, vol. 2, no. 1, pp. 6–11, 2010, [Online]. Available: http://zipcodezoo.com/glossary/pectoral_fin.asp

[71] B. O. Offem, Y. Akegbejo-Samsons, and I. T. Omoniyi, "Biological assessment of *Oreochromis niloticus* (Pisces: Cichlidae; Linne, 1958) in a tropical floodplain river," *African Journal of Biotechnology*, vol. 6, no. 16, pp. 1966–1971, 2007, doi: 10.5897/ajb2007.000-2300.

[72] P. Hunke, R. Roller, P. Zeilhofer, B. Schröder, and E. N. Mueller, "Soil changes under different land-uses in the Cerrado of Mato Grosso, Brazil," *Geoderma Regional*, vol. 4, pp. 31–43, 2015, doi: https://doi.org/10.1016/j.geodrs.2014.12.001.

[73] J. Scott Angle, "Nitrate leaching losses from soybeans (Glycine max L. Merr.)," *Agriculture, Ecosystems & Environment*, vol. 31, no. 2, pp. 91–97, 1990, doi: https://doi.org/10.1016/0167-8809(90)90212-V.

[74] P. Sulai, S. Nurhidayu, N. Aziz, M. Zakaria, H. Barclay, and B. Azhar, "Effects of water quality in oil palm production landscapes on tropical waterbirds in Peninsular Malaysia," *Ecological Research*, vol. 30, no. 5, pp. 941–949, 2015, doi: 10.1007/s11284-015-1297-8.