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Fish Communities of Tropical Headwater Streams Under Multiple Land-use Influence

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ABSTRACT

The intensive development of agricultural activities can be a major threat to the extinction of fish fauna in the tropical headwater streams of Borneo Island. Insufficient information on the influence of multiple land-use on fish communities can lead to failure in preserving ecological buffer zones along stream channels and the loss of aquatic biodiversity. We investigated fish communities of tropical headwater streams in Bau District of Sarawak State that flow through different types of land-uses. It is hypothesised that multiple land-use influent fish diversity and abundance. Fish were sampled at three headwater streams, Sg Bu'un, Sg Dian and Sg Sibomou of Sarawak Kanan River that have multiple land use in the catchment areas. The assessment of land use activities and fish sampling were done once in dry and rainy months. The assessment of land use showed that the distribution of agricultural activities is not consistent across the water catchments of the three headwater streams, which among others could be depending on soil fertility and the interests of the farmers. Oil palm plantation was the major agricultural activity in the catchment of headwater streams. The aboveground biomass varied with the type of land use, size of coverage, and age of the forest or plantation. The fish fauna of the three headwater streams was represented by 25 species in ten families and six orders, which was dominated by the family Cyprinidae. The cyprinids made up 17% of the total individuals with three dominant species are *Barbodes sealei*, *Rasbora cryptica* and *Oxygaster anomalura*. The diversity index of Shannon was significantly different among the three headwater streams. The headwater streams with high coverage of oil palm plantations showed significantly low species richness and high number of individuals. Fish richness and abundance in dry season were significantly lower than rainy season. The less sensitive species such as *Systomus rubripinnis*, *B. sealei*, *R. cryptica* and *Parachela oxygastroides* were dominant in three headwater streams in both wet and dry months. The findings of this study may suggest that the width of buffer zone along stream channel could be estimated by integrating size of the major land use in the catchment, precipitation, and management practices of each type of land-use.

Keywords: Agriculture, Borneo, deforestation, fish assemblages, Sarawak

INTRODUCTION

The river ecosystem in Asian countries is exceptional rich of biota as well as high endemicity (Dudgeon, 2000) and support livelihoods of many communities live in the river basin (Rachmatika *et al*., 2005; Olson & Morton, 2018; Funge-Smith & Bennett, 2019). Extensive exploitation of river resources combined with disturbance and pollution from land use activities have contributed a severe threat to the ecosystem and the biodiversity which led to food security issue in concern. However, the present data are insufficient for identifying specific source of each environmental problem. The environmental problem is accelerated over the years and increasingly difficult to manage due to new forms of pollution and disturbance introduced to the rivers. The major challenges in managing environmental problem of river system are due to the difficulty to identify and deal with multiple-stressor effects (Ormerod *et al*., 2010). The effect of multiple stressors varies from upstream to river mouth of which each section of the river has different carrying capacity to dilute the effects. The changes in water catchment resulting from agriculture activities have a negative effect on fish communities (Trautwein *et al*., 2012; Wilkinson *et al*., 2018). The effect

is expected to be more severe in the headwater stream with relatively low carrying capacity than in large rivers. The water catchment of headwater streams is most fertile and thus suitable for various agriculture activities. In Borneo, multiple land use on a water catchment is common that involves small-scale subsistence farming and large plantation. The common agriculture activities in a catchment are oil palm, rubber, hill rice field, pepper, and fruit garden (Grifin, 2014; Sapis, 2014). Each agriculture activity applies a different approach of management in increasing the yield and controlling the pests and weeds. The combination of various sources of pollutants and magnitude of disturbance from several types of land use poses a difficulty in understanding the major effect of the activities on headwater stream quality and the fish diversity. The lack of information on this environmental problem has resulted in the failure in protecting the headwater stream and the aquatic biodiversity.

Therefore, this study investigated the fish communities of headwater streams flowing in various type of land uses in the State of Sarawak, Malaysia in southwestern Borneo Island. It is hypothesised that multiple land use activities contributed a significant effect on fish communities in headwater streams. The study centered at the headwater drainages of Sarawak River that are an essential source of water supply for the population in the Kuching Division. It is fed by two major tributaries, the Sarawak Kanan and Sarawak Kiri. The catchment of the tributaries is composed of limestone, dipterocarp and health forests. Many headwater streams are used for recreational and eco-tourism activities. The villagers used the streams as a source of fish, prawns, crabs, and snails for sale and own consumption. Agricultural activities have been practiced in the catchment of the headwater streams in various scales.

MATERIALS AND METHODS

Study Site

The study was conducted at three headwater tributaries of the Sarawak Kanan River; Sg Bu'un, Sg Dian, and Sg Sibomou, which are categorised as the second-order streams (Figure 1). These headwater streams are located in the southwest of Kuching Division that flow to Sarawak River or Sambas River in West Kalimantan, Indonesia. The catchment of the streams comprised oil palm plantation, intensive farming, old secondary forest, young secondary forest, open area, and bushes. Oil palm plantation constitutes the primary coverage of the catchment of Sg Bu'un and Sg Dian, whereas old secondary forest is the major coverage of the catchment of Sg Sibomou. The condition of riparian forests along the stream channels varies with slopes and the intensity of the agricultural activity. The water of the streams is clear during the dry season and muddy in the rainy season.

Assessment of Land-use

The boundaries and size of each catchment and land use were estimated using Google Earth Pro, ArcGIS 10.3, GPS, and satellite images. The ground inspection was conducted to verify the digital maps (Figure 1). The land use in each stream was classified into six categories according to the estimated age of use and magnitude of land use activity following the method of Sapis (2014). The assessment identified six categories of land-uses: open area (OA), old secondary forest (OF), oil palm plantation (OP), bushes (BS), young secondary forest (YF), and intensive farming (IF) (Table 1, Figure 1). The area and type of land use were estimated by using Spatial Analysis Tools in ArcGIS 10.3 and Google Earth Pro. The boundaries and land uses were demarcated with the aid of a topography map from the Department of Survey and Mapping Malaysia. On the ground, plot inventory was conducted to estimate the aboveground weight biomass (AGB) content within each land use type found in the stretch of the stream except for bush area. A systematic plot inventory was conducted within the 10 m strip of vegetative cover on both sides of the riverbanks. The inventory plot has a size of 10 m × 10 m and was divided into four subplots. Tree species in each subplot were counted and identified to generic or species level. The tree diameter at breast height (DBH) of 5 cm was measured with a diameter tape. The data were used to estimate the aboveground biomass in each type of land use (Table 1). The estimation of aboveground biomass was compared with other catchments in the Sarawak Kiri River (Sapis, 2014), which allow for the validation of the present data.

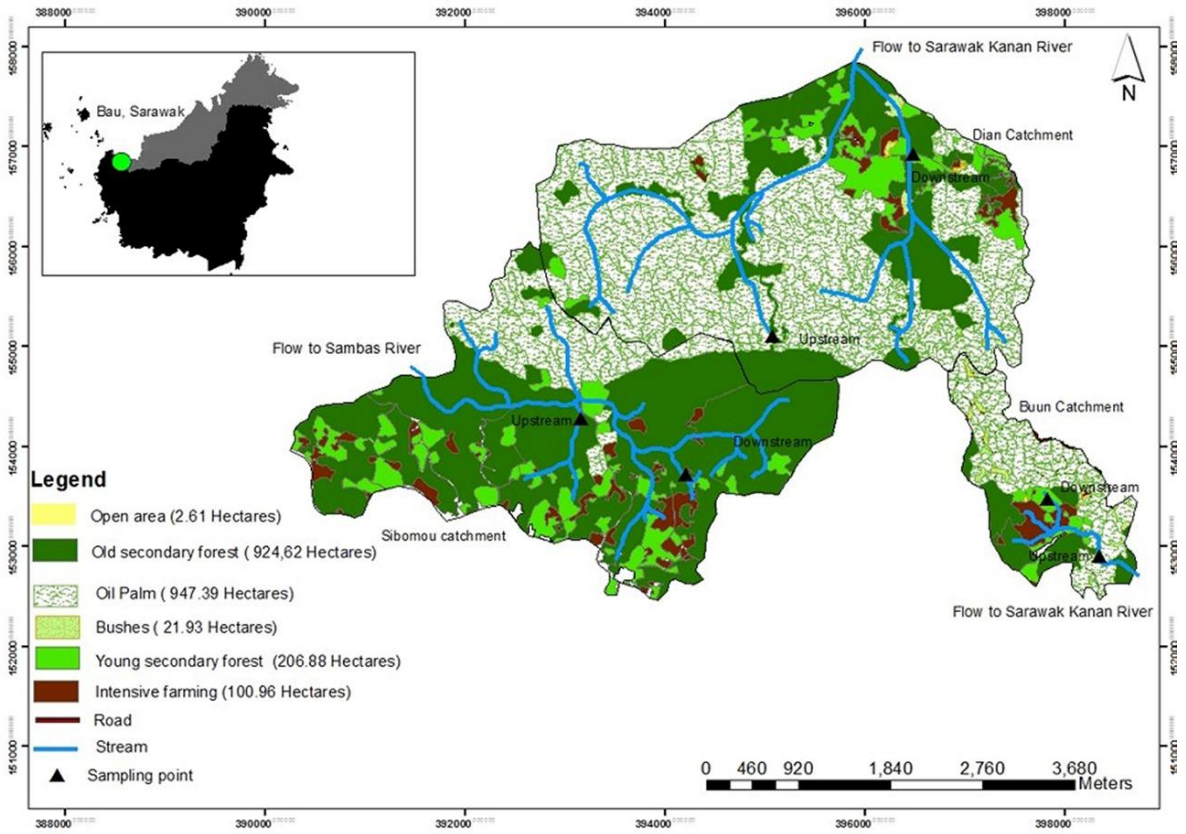

Figure 1. Map of multiple land-use and sampling points

Table 1. Five types of land-use in the headwater streams and the descriptions (Sapis, 2014)

Types of land-use	Descriptions
Oil palm plantation	Oil palm plantation is divided into 2 ages with 10 to 15 years and 16-25 years (age data obtained from the plantation owners). In general, these lands are ongoing of clearing maintenance and harvesting. The typical above ground dry weight biomass (ABG) content for this type is 50 metric tons per hectares for 10-15 years and 80 metric tons per hectares for 15-25 years.
Intensive farming system	Intensive farming refers to cultivation activities that consists of rice, cocoa, rubber and pepper. Generally, this cultivation is cultivated actively especially rice fields where some of it are newly generated. The typical above ground dry weight biomass content for this type is 5 metric ton per hectares.
Bushes	Growing with small branches either directly from the ground or from a hard stem. Usually, an area covered with bushes are an area that has never been used for growing crops.
Young secondary forest	This category is previously cultivated by rice fields or other agriculture activities. These lands are generated back to forest and classified as young secondary forest with age of 3 to 15 years old. Usually, the above ground dry weight biomass content is 75 ton per hectares.
Old secondary forest	Old secondary forests are made from previous agriculture activities or logging activities and left abandoned for so long. The ages of typical old secondary forest are more than 20 years with above ground dry weight biomass content of 150 ton per hectares.

*Aboveground biomass comprises plant materials above the soil such as stems, branches and leaves, therefore, ABG = WS + WB + WL, where WS = weight of stems, WB = weight of branches, WL = weight of leaves.

Fish Sampling and Identification

The fish sampling was conducted twice (wet and dry month) at downstream and upstream sections of the headwater streams. The fish were collected by using gillnets, cast nets, and electroshocking. Gillnets and cast nets were used at deep sections. Electroshocking was employed at shallow sections. Three gillnets (mesh size: 2.5 cm, 5.1 cm, 6.4 cm) were placed in deep sections for two-consecutive nights and checked every morning. The cast net (measurement: 3.6 m long; 2.5 cm mesh size) was thrown 10 times at each site. Electroshocking was done at a distance of 40 – 100 m in each section. Fish were identified at the species level following the keys of Kottelat *et al*. (1993), and the taxonomic was verified with a fish catalog of Southeast Asia (Kottelat, 2013). The fish specimens were measured for weight (to 0.1 g), total length (0.1 cm), and standard length (to 0.1 cm).

Data Analysis

The Shannon diversity index was calculated and tested for significant differences between streams at a 0.05 significance level in PAleontological STatistics (PAST) program (Hammer *et al*., 2001). A multiple linear regression was performed to determine if parameters of land use (i.e., size of each land use and aboveground biomass) significantly predict the fish metrics (i.e. abundance and richness). The analysis was done in Jeffreys's Amazing Statistics Program (JASP) program. Principal components analysis was used to explore assemblages of fish across types of land use. It was run on log-transformed data and 1000 permutation was performed to validate the usefulness of the axes of the PCA. The analysis was run in PC-ORD package (McCune & Mefford, 2018).

RESULTS

The total area of the catchment of the three headwater streams was estimated at about 2,415.9 hectares, consisting of six types of land use (Table 2, Figure 1). The catchments are mainly covered by oil palm plantations (946.4 ha) and old secondary forests (924.9 ha). The distribution of land use activities is not consistent across the three catchments. For instance, oil palm plantation was relatively prominent in the catchment of Sg Dian (57.99%) and Sg Bu'un (39.22%), whereas the catchment of Sg Sibomou was dominated by old secondary forest (64.79%).

The assessment showed that the aboveground biomass varied with type of land use, size of coverage, and age of the forest or plantation (Table 1 & 3). The aboveground biomass was relatively higher in Sibomou's catchment which dominated by old secondary forest. In oil palm plantation, the aboveground biomass was relatively higher in older plantation (80 metric tons/ha in 16 – 25 years old) than the younger plantation (50 metric tons/ha in 10 – 15 years old). The stages of oil palm plantation indicated the intensity of the agricultural activity in the catchment. For example, the intensity of oil palm plantation in Dian's catchment was relatively higher, which consisted of oil palm plantation of the 10 – 15 years and 16 – 25 years old. In Bu'un's and Sibomou's catchment, the oil palm plantation had only stage of 10 – 15 years and 16 – 25 years, respectively. The estimate aboveground biomass increased by the age of oil palm plantation. It was also observed that the aboveground biomass was associated with the activity of controlling of weeds and maintenance of the access roads.

The study recorded a total of 536 individuals of fish in six orders, 10 families and 25 species (Table 4). The fish fauna of the three headwater streams was dominated by family Cyprinidae, in which, it is a typical fish community structure in freshwater ecosystem in Borneo and other Southeast Asia countries (Roberts, 1989; Kottelat *et al*., 1993). The family Cyprinidae made up 17% of the total individuals comprising three dominant species i.e., *Barbodes sealei*, *Rasbora cryptica* and *Oxygaster anomalura*. The diversity index of Shannon was significantly different among the three headwater streams (i.e., Sg Bu'un vs. Sg Dian, $t = 3.688$, $df = 143.37$, $p = 0.0003$; Sg Bu'un vs. Sg Sibomou, $t = -2.631$, $df = 203.14$, $p = 0.0092$; Sg Dian vs. Sg Sibomou, $t = -4.969$, $df = 222.87$, $p = 1.34 \times 10^{-6}$) (Figure 2). The headwater stream with large coverage of oil palm plantation (i.e. Sg Dian) has significantly low species richness, and high number of individuals (Figure 2).

Table 2. Summary of forest inventory (ha) in each headwater stream. OA, open area; OF, old secondary forest; OP, oil palm plantation; BS, bushes; YF, young secondary forest; IF, intensive farming

Land-use	Headwater catchment			Total
	Sg Bu'un	Sg Dian	Sg Sibomou	
OA	18.6 (6.37%)	39.6 (3.30%)	25.1 (2.72%)	83.3 (3.45%)
OF	39.1 (13.38%)	288.0 (23.98%)	597.8 (64.79%)	924.9 (38.28%)
OP	114.6 (39.22%)	696.4 (57.99%)	135.4 (14.67%)	946.4 (39.17%)
BS	79.5 (27.21%)	72.2 (6.01%)	1.8 (0.20%)	153.5 (6.35%)
YF	15.3 (5.24%)	80.4 (6.69%)	111.2 (12.05%)	206.9 (8.56%)
IF	25.1 (8.59%)	24.4 (2.03%)	51.4 (5.57%)	100.9 (4.18%)
Total	292.2	1,201.0	922.7	2,415.9

Table 3. The estimated above-ground biomass (metric tons/ha) for each type of land-use in three catchments. OA, open area; OF, old secondary forest; OP, oil palm plantation; BS, bushes; YF, young secondary forest; IF, intensive farming

Land-use	Headwater catchment			Total
	Sg Bu'un	Sg Dian	Sg Sibomou	
OA	0	0	0	0
OF	193.4	1,439.8	257.2	1,890.4
OP	5,780.5	34,817.0	2,007.2	42,604.7
BS	56.8	51.6	1.2	109.6
YF	1,149.0	6,027.0	8,340.0	15,516.0
IF	125.3	122.2	257.2	504.7
Total	7,305.0	42,457.6	60,625.6	121,250.8

Table 4. Fish species and the occurrence in three headwater streams. Sg Bu'un (BN), Sg Dian (DN), Sg Sibomou (SU)

Taxon	BN	DN	SU
CYPRINIFORMES			
Cyprinidae			
Barbodes banksi (Herre, 1940)	•	•	•
Barbodes kuchingensis (Herre, 1940)	•	•	
Barbodes lateristriga (Valenciennes, in Cuvier & Valenciennes, 1842)			•
Barbodes sealei (Herre, 1933)	•		
Cyclocheilichthys apogon (Valenciennes, in Cuvier & Valenciennes, 1842)	•		•
Hampala bimaculata (Popta, 1905)	•	•	•
Hampala macrolepidota (Kuhl & van Hasselt, 1823)	•		
Osteochilus enneaporos (Bleeker, 1852)			•
Parachela oxygastroides (Bleeker, 1852)	•	•	•
Puntigrus anchisporus (Vaillant, 1902)		•	
Rasbora calliura (Boulenger, 1894)	•	•	•
Rasbora cryptica (Kottelat & Tan, 2012)	•		
Rasbora sarawakensis (Brittan, 1951)			•
Systomus rubripinnis (Valenciennes, in Cuvier & Valenciennes, 1842)	•		

Table 4. Continued

Taxon	BN	DN	SU
Nemacheilidae			
Nemacheilus saravacensis (Boulenger, 1894)	•		•
SILURIFORMES			
Clariidae			
Clarias leiacanthus (Bleeker, 1851)	•		
BELONIFORMES			
Belonidae			
Xenentodon canciloides (Bleeker, 1854)			•
Zenarchopteridae			
Hemirhamphodon byssus (Tan & Lim, 2013)	•	•	•
GASTEROSTEIFORMES			
Syngnathidae			
Doryichthys deokhatoides (Bleeker, 1854)			•
SYNBRANCHIFORMES			
Mastacembelidae			
Macrognathus aculeatus (Bloch, 1786)			•
Macrognathus keithi (Herre, 1940)			•
Macrognathus maculatus (Cuvier, in Cuvier & Valenciennes, 1832)	•	•	
PERCIFORMES			
Pristolepididae			
Pristolepis fasciata (Bleeker, 1851)			•
Gobiidae			
Brachygobius doriae (Günther, 1868)			•
Channidae			
Channa lucius (Cuvier, in Cuvier & Valenciennes, 1831)	•		•

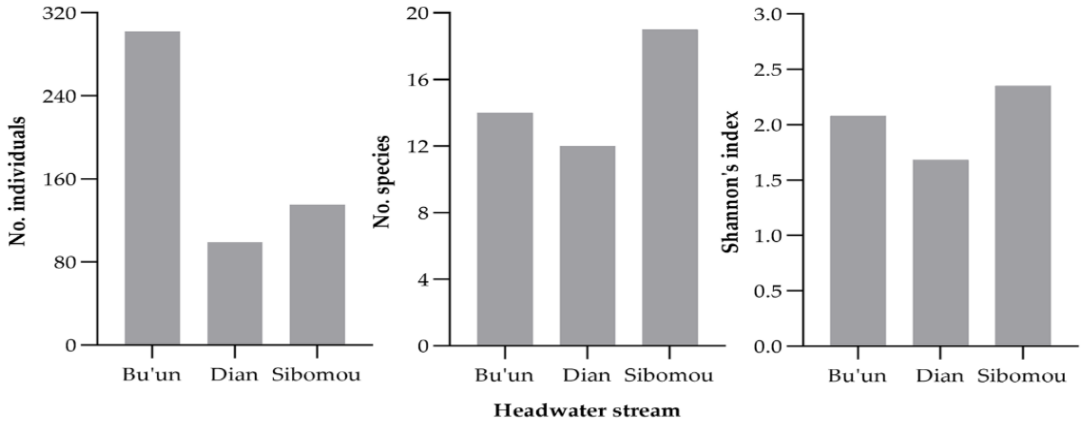

Figure 2. Summary of fish fauna from three headwater streams. The comparison t-test of Shannon's index between streams all are significant at $p<0.05$

The principal component analysis showed 48% of the total variance (i.e. Axis 1) of the fish abundance was associated with headwater streams which imply a relationship between fish community and type of land use (Figure 3, p = 0.001). The second axis of PCA (i.e. Axis 2) showed 16% of the total variance of fish abundance which was associated with the time of sampling suggesting the season potentially contributed to the changes in fish community (Figure 3, p = 0.001). The distribution of fish species seemed to associate with their tolerance to disturbance from land use activities. For example, four species of cyprinids (i.e. *Systomus rubripinnis*, *Barbodes sealei*, *Rasbora cryptica* and *Parachela oxygastroides*) were dominant in three headwater streams in both wet and dry months might have indicated the species are tolerant to disturbance. In comparison, the typical species of headwater stream such as family Gastromyzontidae (Tan, 2006) was absent from the headwater streams, which might be due to their sensitivity to disturbance. The multiple regression analysis showed the parameter of land use (i.e. size of each land use and aboveground biomass) has not significantly predicted the abundance and richness of the fish communities (Table 5), which may suggest no direct effect of the parameters on the fish fauna.

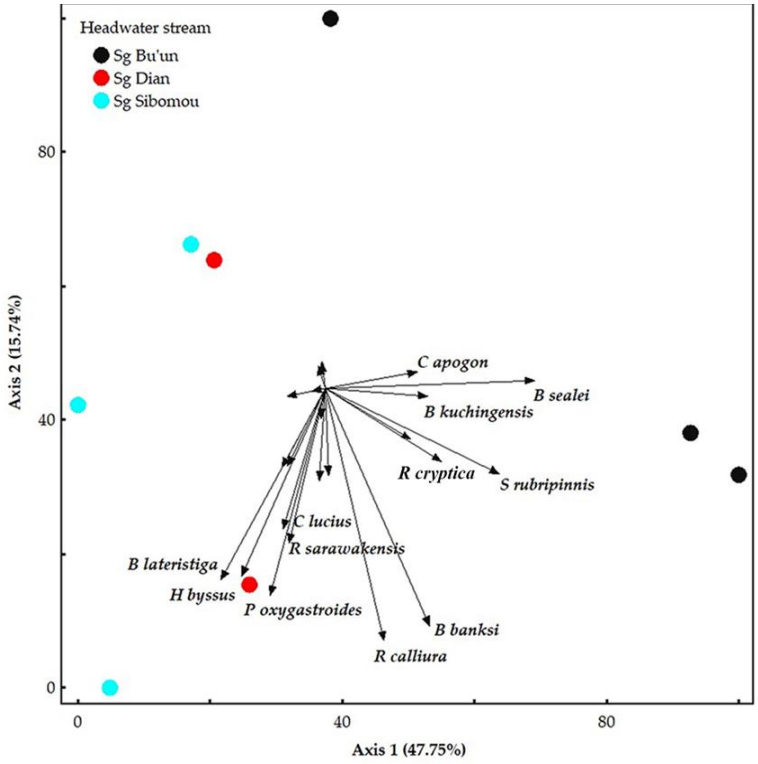

Figure 3. Biplot of principal components analysis of relationships among species and the fish assemblages in the three headwater streams. Permutation test showed a significance importance of Axis 1 (water catchment) and Axis 2 (season) at p = 0.001

Table 5. Summary of linear regression between fish metric and parameters of land use

Parameters	R^2		Regression coefficient		t statistic, p-value	
	Abundance	Richness	Abundance	Richness	Abundance	Richness
Total area	0.797	0.013	-0.201	-3.71×10^{-4}	-6.874, 0.092	-0.114, 0.928
OA	0.699	0.273	-7.365	-0.074	-1.523, 0.370	-0.613, 0.650
OF	0.540	0.491	-0.249	0.004	-1.083, 0.475	0.983, 0.506
OP	0.429	0.540	-0.188	-0.003	-1.084, 0.474	-0.867, 0.545
BS	0.189	0.835	-0.960	-0.033	0.483, 0.714	-2.247, 0.267
YF	0.788	0.238	-1.717	0.015	0.559, 0.675	-1.926, 0.305
IF	0.112	0.907	-2.063	0.094	-0.356, 0.782	3.114, 0.198
ABG	0.770	0.257	-0.003	2.86×10^{-5}	-1.827, 0.319	0.588, 0.661

DISCUSSION

The pattern of multiple land use practiced by native communities is similar across Borneo after which oil palm plantation was first introduced in Sarawak in 1976 (Sangin & Mersat, 2013) and followed by rapid expansion in the mid-1990s (Fold & Hansen, 2007). For the study site in Bau area, the Sarawak Land Consolidation and Rehabilitation Authority have established a joint venture with local communities to develop substantial areas for oil palm plantation on Native Customary Right land (Sangin & Mersat, 2013). In addition to the large scale of oil palm plantation, the local communities have also planted other cash crops at adjacent forests. Obviously, the management of each land use (e.g. controlling of weeds) vary with the type of crops and the purpose of the agriculture activities. The management practices contribute a significant variation in the content of aboveground biomass of different land use. Morel *et al.* (2012) demonstrated that a higher aboveground biomass in oil palm than nearby forests for nine years' data in oil palm plantation in Sabah. The variability of the estimated aboveground biomass among types of land use might have due to vegetation saturation (Singh *et al*., 2014). However, no study had been done prior to each agricultural activity taking place thus quantifying of the effects of a single activity within a multiple land use area on river ecosystem and biodiversity is very challenging.

The impacts of land-use activities on terrestrial and aquatic biodiversity in Sarawak have been discussed of which oil palm plantations and palm oil mills are considered as the major threats (Hon & Shibata, 2013; Grifin, 2014; Sapis, 2014). Martin-Smith (1998) showed a significant variation in fish richness and composition at different stations of small streams flow through catchment with selective logging activity in Sabah. Inoue *et al.* (2003) demonstrated past deforestation (e.g. slash-and burn for subsistence farming) by local communities has significant effect on fish assemblages at different sections of small streams in Sarawak. Our results indicated that the sampling stations directly influenced by oil palm plantation have severe bottom sedimentation and habitat degradation. The muddy bottom substrates are unstable and cause the water rapidly to turn from clear to turbid between sunny and rainy days. The effect of this unstable habitat was demonstrated in low number of species of which they populated in abundantly possibly less competition for food. The accumulated oil palm fronds in the streams during maintenance stage have altered habitat quality and reduce space for many species. This was demonstrated in Sg Sibomou which has significantly less coverage of oil palm plantation and substantially intact with secondary forest area as compared to Sg Bu'un and Sg Dian. The presence of five benthic feeders (i.e. *Doryichthys deokhatoides*, *Osteochilus enneaporos*, *Macrognathus aculeatus*, *M. keithi* and *Brachygobius doriae*) only in Sg Sibomou may indicate the fish species are sensitive to sedimentation, thus absent from Sg Bu'un and Sg Dian.

Fish diversity and abundance were relatively higher in wet season than in dry season as shown in principal components analysis (Figure 3). The habitats in wet season were diverse where floodplain is expanding to a large area especially at low gradient channel. The high water level might have permitted fish movements from the main river channel to the study sites. In addition, the food source (i.e. allochthonous foods of terrestrial arthropods and seeds) could also relatively diverse and abundant during the wet season. In contrast, some sections of stream channels were cut-off during dry season which is obvious within the oil palm plantation. Therefore, the fish might have been trapped in the disconnected shallow pool during long dry period. The trapped fish could have potentially been exposed to predators such as migratory egrets, otters and monitor lizards, and as well mass death due to lack of dissolved oxygen and heat. The food source could also be scarce and less diverse during the dry season. The results of the study demonstrated that the composition of fish in headwater streams is associated with type of land use, but no direct effect of size of each land use, and aboveground biomass on the fish communities. The environmental policy of Sarawak government requires 5 – 50 m wide of natural vegetation to be retained along all rivers, which serve as buffer of environmental problems. The width of the buffer strip is determined based on the river width (Ligtermoet *et al*., 2009). The findings of this study may suggest that the width of buffer strip should be estimated by integrating size of the major land use in the catchment, precipitation and management practices of each type of land-use.

CONCLUSION

The variability of type of land use, age of the forest or plantation, size of coverage and aboveground biomass in the catchment create a complex form of disturbance to headwater streams and the fish communities. The study demonstrates a low species diversity of fish in headwater streams that flow through multiple land use activities. The study recorded 25 species in ten families and six orders, many of which can be considered as disturbance tolerant fish (i.e. *Systomus rubripinnis*, *Barbodes sealei*, *Rasbora cryptica,*and *Parachela oxygastroides*). Although the composition of fish fauna is associated with the type of land use, there is no direct effect of land use coverage and aboveground biomass on species richness and abundance. For example, the species that prefer shaded waterways such as *Doryichthys deokhatoides, Osteochilus enneaporos, Macrognathus aculeatus, M. keithi* and *Brachygobius doriae* were only found in land use with high coverage of secondary forest. The study suggests that the ecological buffer zone along the stream channel should be preserved. The size of the buffer zone should integrate the size of the major land-use in the catchment, precipitation and management practices of each type of land-use. For the future study, it is important to determine if multiple land use activities in the catchment of headwater streams associated with the fertility of the soil and the interests of the farmers towards the crops.

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