THE AQUATIC INVERTEBRATES ASSEMBLAGES RESPONSES TO WATERSHED LAND USE IN TABIN WILDLIFE RESERVE (TWR), LAHAD DATU, SABAH, MALAYSIA

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ABSTRACT. *A study on the aquatic invertebrate communities was conducted at Tabin Wildlife Reserve (TWR), Lahad Datu, Sabah, with the objectives to study (i) the diversity of aquatic invertebrates across different land use, (ii) the composition of aquatic invertebrates in different habitats and microhabitats in the stream, and (iii) the relationship between invertebrates and the water quality of the stream. Sampling was done at Sg. Lipad which flows across the secondary forest area and plantation area. Kick net method was used to sample the aquatic invertebrates for 14 continuous days in January to February 2015. A total of 3,579 individuals were sampled consisting of 76 families from eight orders, in both of the land uses. The diversity of aquatic invertebrates in the secondary forest was found to be slightly higher than plantation area with H'= 3.213 and H'= 3.188 respectively. The aquatic invertebrates were also found to be more abundant in riffle habitat, and the least in pool habitats. The diversity for pool habitat, however, was the highest among all other habitats with H'= 3.709. Both physico-chemical parameters and biotic indices indicated that the invertebrate communities were affected by the water quality in the surroundings, and may be used for rapid assessment of water quality at TWR.*

INTRODUCTION

Aquatic ecosystems had been recognised as one of the most threatened components of global biodiversity in the world despite its richness of biodiversity (Dudgeon et al., 2006; Sala and Jackson, 2006). Ricciardi and Rasmusse (1999) stated that the lack of understanding towards aquatic biodiversity, and studies suggesting that the rate of extinction of freshwater fauna were much higher than those of terrestrial species, had urged for the attention that was needed to conserve biodiversity as a whole. Although there had been highlight on global diversity issues, however, Strayer and Dudgeon (2010) argued that less attention was focussed on the loss of biodiversity in tropical aquatic ecosystems.

Biodiversity reduction or the alteration of species composition was one of the common side-effects of biological pollution on the ecosystems (Goldburg and Triplett, 1997). Ansah *et al.* (2012) stated that due to the response of the organisms which resided in the aquatic ecosystems towards chemical and physical properties of their environment, they were being widely used as a complement or sometimes as an alternative to chemical and toxicity testing.

In an aquatic ecosystem that is intact structurally and functionally, water is readily to be used or suitable for use after a simple treatment (Karr and Chu, 2000). In such a river, its water body has a level whereby the assimilative capacity of pollutants has not been exceeded (Tucker *et al.*, 2002). It has been found in many cases where the use of aquatic biota in water quality tests has yielded reliable signals of the effects of pollutants or habitat alteration, serving as the basis for direct biological assessment and monitoring (Karr and Chu, 2000). This renders biomonitoring for more feasible and low-cost alternatives or as a complement to chemical measurements and toxicological bioassays.

There were a number of aquatic organisms which had been proposed and used for the assessment of water quality. However, fishes (Peterson *et al.*, 2011) and macroinvertebrates (Burghelea *et al.*, 2011) were two of the most commonly used and recommended organisms in biomonitoring. Macroinvertebrates and fishes can be found at almost everywhere within the aquatic habitat as they are well adapted to different habitats of each of the river systems, enabling them to be used in various environmental perturbations of their habitats (Scardi *et al.*, 2006). In conjunction with the increasing study and identification of aquatic macroinvertebrates, there are numerous identification keys and guides for aquatic macroinvertebrates across different regions all around the world (Hartmann, 2007). The collection and identification of aquatic macroinvertebrates have become relatively easier, and thus making it a more suitable biotic assessment tool (Scardi *et al.*, 2006). Thorne and Williams (1997) explained that such a relatively low cost with low technical requirement method of water quality assessment would be particularly useful for a developing country.

Due to the fact that aquatic ecosystems researches are lagging behind that of other ecosystems, particularly the terrestrial ecosystems (Linke *et al.*, 2011), it would thus make the incorporation of aquatic ecosystems into conservation planning much more difficult (Woodward *et al.*, 2010). Therefore, in parallel to Linke *et al.* (2011), the consideration of land cover type impacts towards the biodiversity and ecosystem function within the streams have to be included into conservation planning.

Despite the progressing efforts being invested on conservation in Malaysia, Yule and Gomez (2009) indicated that some of the aquatic ecosystems in Malaysia had been degraded or destroyed to a stage that they had lost the pristine conditions. In Malaysia, there had been a decrease of more than half in terms of the percentage of clean water from year 2008 to 2012, based on the Ammoniacal Nitrogen pollutant (Department of Statistics Malaysia, 2013).

Tabin Wildlife Reserve (TWR) was gazetted under Sabah's Forest Enactment 1984 as a Class VII Wildlife Reserve with the main priority to protect endangered wildlife, particularly as the breeding ground for three large mammals found in Borneo (World Wildlife Fund Malayisa, 1986). As recommended by Che Salmah *et al.* (2013), intensive ecological research to investigate drivers regulating the community structure of aquatic invertebrates in Southeast Asian streams should be carried out. Therefore, this study would serve as a contribution to the existing information regarding the composition and diversity of aquatic invertebrate communities at Tabin Wildlife Reserve.

Aquatic invertebrates from the streams of different types of land-use in TWR have been examined together with water quality of the streams to investigate the impact of logging and agricultural activities towards the aquatic communities. Effects of reduced disturbance from anthropogenic activities through conservation efforts that had been ongoing for decades may allow the ecosystem to achieve its dynamic equilibrium (Tyson, 2000). The objectives of this study were to study (1) the diversity of aquatic invertebrates in the stream of different types of land use at TWR, (2) the composition of the aquatic invertebrates in different habitats and microhabitats at TWR, and (3) the relationship between invertebrates and the water quality of the streams at TWR.

MATERIALS & METHODS

Study Area

Tabin Wildlife Reserve (TWR) has been gazetted since 1984 to preserve the disappearing wild animals in Sabah (Sale, 1994). Tabin Wildlife Reserve (TWR) is inclusive of two types of forest reserve, namely Class 7 Wildlife Reserve and Class 6 Virgin Jungle Reserve, located in the middle of the Dent Peninsula, northeast of Lahad Datu (Sale, 1994). The surroundings of Tabin Wildlife Reserve, that are still unprotected, have been used for agricultural purposes, in specific, oil palm plantation which is currently enclosing the whole perimeter of TWR. Forest surrounding TWR was logged selectively for timber products, and only an area of 8,616 hectares, which is about 10% of the original coverage, has been retained as the Core Area for the reserve and has never been licenced for logging (Sale, 1994). The total size of TWR is 120,521 ha, comprising of mainly lowland forest, and the highest peak is Mount Hatton at 571 m above sea level (asl).

Samplings were conducted in the Sg. Lipad, which flowed across the secondary forest area at the upstream section, and oil palm plantation at the downstream section. Samplings were done at four stations along Sg. Lipad, where two stations were located at the upstream, while another two at the downstream. A 100 m range of the stream was selected for each sampling site. There was an approximately 500 meter distance between upstream and downstream stations.

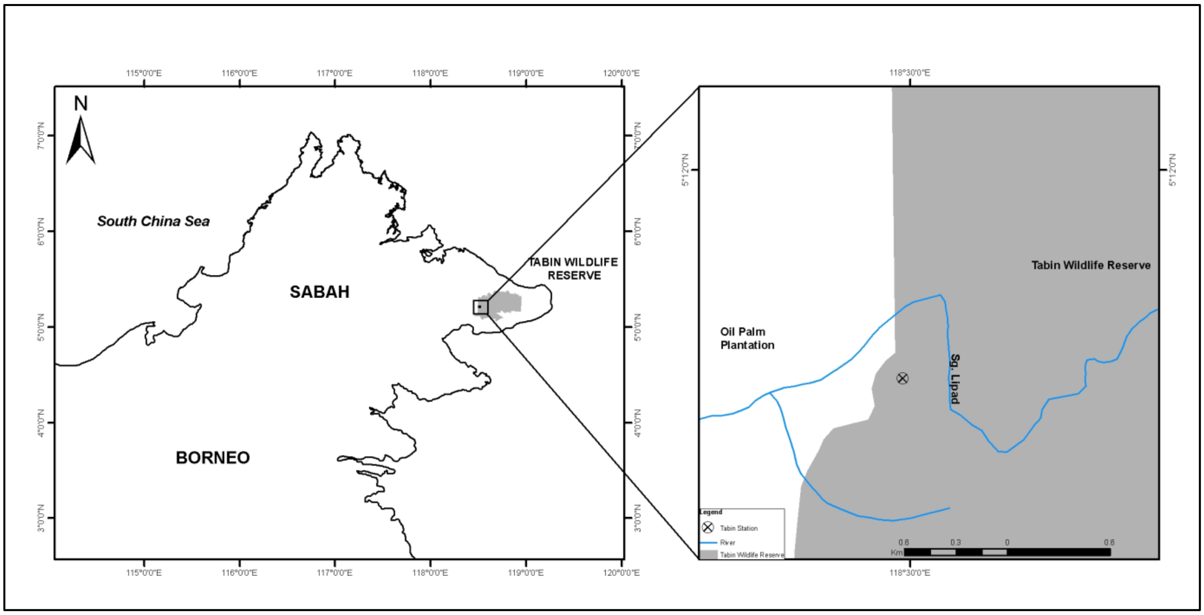

Figure 1: Map shows Sg. Lipad in Tabin Wildlife Reserve

Sampling Freshwater Invertebrates and Water Quality

Sampling and collection of invertebrates were done in three habitats which were pools, runs, and riffles, with one microhabitat of leaf litter in the streams at TWR. Three replicates were done at each habitat of pool, run and riffle, as well as the leaf litter at each station.

Sampling processes were done in January to February, 2015 for a total duration of two weeks. Sampling period for one day was approximately eight hours and 48 minutes. Sampling was done at 0800-1700h for each day at one stream. Kick-net method was used for the aquatic invertebrates sampling process. Substrates and invertebrates clinging on the stones were washed downstream into the net by disturbing the substrates and rubbing larger stones (Basin and Denham, 2011). The specimens were placed and sorted in white. Sorted specimens were preserved in 95 % of ethanol and been identified to family level (Yule & Yong, 2004)

The HANNA multi-parameter meter (Model: HI9818) was used to record the pH, dissolved oxygen, conductivity and water temperature of the stream. Three readings of each water quality parameter were taken at the starting, middle and ending point of the sampling station.

RESULTS AND DISCUSSION

From the sampling done at TWR, a total of 3579 individuals of aquatic invertebrates were collected from eight orders and 76 families (Table 1). Of all the 3,579 individuals sampled, 1,404 individuals were obtained from stream situated at oil palm plantation area, while 2,175 individuals were from the secondary forest area (Table 2). The samplings were done at Sg. Lipad with the upper stream being situated within the secondary forest area and flowing down across plantation area. The most diverse order of invertebrates collected from the stream at Tabin Wildlife Reserve was Diptera with a total of 16 families. However, Ephemeroptera yielded the most number of individuals with a total of 1,549 individuals, followed by Coleoptera with 675 individuals, while the least number of individuals obtained was from the order Megaloptera with 51 individuals.

Table 1: Total number and percentage of aquatic invertebrate families and individuals from Sg. Lipad of TWR.

Order	Number of family	Percentage family (%)	Number of individuals	Percentage of individuals (%)
Coleoptera	11	14.47	675	18.86
Diptera	16	21.05	435	12.15
Ephemeroptera	11	14.47	1549	43.28
Hemiptera	10	13.16	197	5.50
Megaloptera	2	2.63	51	1.42
Odonata	9	11.84	132	3.69
Plecoptera	7	9.21	216	6.04
Trichoptera	10	13.16	324	9.05
Total	**76**	**100**	**3579**	**100**

A similar study was done by Fikri (2004) conducted more than 10 years ago at TWR to compare between the aquatic invertebrate communities at different forest types. In comparison to the study done by Fikri (2004), a total of 12,960 individuals of aquatic invertebrates representing 10 orders from 52 families were collected from rivers in three different forest types. There was a difference between the diversity and abundance of aquatic invertebrates from the study by Fikri (2004), and this study which might be due to the number of habitats and microhabitats sampled. In this study, the aquatic invertebrates were sampled from three habitats (pool, run, riffle) and one microhabitat (leaf litter). However, in the previous study, there were more microhabitats covered from stone substrates to vegetation microhabitats (Fikri, 2003). Despite the lower number of orders collected in this study, there were a higher number of families that were sampled in this study as compared to the previous study that was conducted 10 years ago.

Table 2: The number of individuals and percentage of aquatic invertebrates for different land uses at TWR.

Order	Plantation		Secondary	
	Number of individuals	Percentage of individuals (%)	Number of individuals	Percentage of individuals (%)
Coleoptera	255	18.16	420	19.31
Diptera	226	16.10	209	9.61
Ephemeroptera	641	45.66	908	41.75
Hemiptera	87	6.20	110	5.06
Megaloptera	8	0.57	43	1.98
Odonata	71	5.06	61	2.81
Plecoptera	27	1.92	189	8.69
Trichoptera	89	6.34	235	10.81
Total	**1404**	**100**	**2175**	**100**

Ephemeroptera made up of almost half of the total sampled individuals with 43.28%, while Megaloptera constituted of only 1.42%. Ephemeroptera together with Plecoptera and Trichoptera, the EPT communities, sampled during the study consisted of a considerable large proportion of the total individuals with 2,089 individuals or 58.37% of all the sampled individuals. Ephemeroptera, Plecoptera, and Trichoptera are often associated with clean and cool running water (Harun, 2010). These invertebrates rely on oxygen-rich and pollution free water for their survival (Glastris *et al.*, 2001). It can also be inferred that the water flowing in Sg. Lipad is of clean water quality that is able to support these species of invertebrates. In addition, the stream are classified as Class I and IIA based on the dissolved oxygen, conductivity and pH recorded (Table 4).

The order of invertebrates collected which were the second highest in terms of abundance was from the order Coleoptera. Some species of Coleoptera invertebrates were known to live especially well in water which contained high oxygen concentration (Braun *et al.*, 2014). In the study by Jach and Balke (2008), the family Elmidae under Coleoptera was considered as important bioindicators due to their sensitivity towards the changes in physical and chemical conditions in the aquatic environment. The high abundance of the invertebrates from this order could hint the cleanliness of the water in the secondary forest area. Furthermore, with more environmental indicator species from the invertebrates from order Ephemeroptera, Plecoptera, Trichoptera, and Coleoptera, the accuracy of assessment of the water quality would be elevated (Song *et al.*, 2009).

Diptera also consisted of a considerable amount among the collected individuals of aquatic invertebrates with a total of 435 individuals. Invertebrates of the order Diptera played important roles in the aquatic food webs as they were often diverse and abundant due their wide range of habitats, and some which were capable of surviving in heavily polluted water bodies (Bouchard, 2004). Nevertheless, the proportion of the EPT communities over the family Chironomidae from Diptera showed that there was a large difference between the numbers of individuals, and hinted that the water at TWR was rather clean (Mandaville, 2002). The remaining families Hemiptera, Odonata, and Megaloptera made up of about 10% of the total sampled individuals. Among these three orders, Hemipteran species were commonly widespread because of their high dispersal capacity, and ability to withstand a wide range of environmental and anthropogenic conditions that explained their higher number of individuals captured (Carbonell *et al.*, 2011). As for the Megaloptera and Odonata, they were more sensitive to their environment, and thus, were used as water quality indicators by some researcher for measuring the family-level richness (Menetrey *et al.*, 2005).

The invertebrates across different land uses at TWR differed in which aquatic invertebrates at the secondary forest area had more individuals of invertebrates for every invertebrate order, except for the order Diptera. Among the order Diptera, Chironomidae was one of the family generally considered to be related to poor water quality (Oliveira *et al*., 2010; Lento *et al*., 2012). Invertebrates from Diptera order in the secondary forest area composed of 9.61%, while there were 16.10% in plantation area. This showed that the water at the secondary forest area was relatively cleaner as compared to the plantation area. The EPT communities to Chironomidae ratio for the secondary forest area (32.49) were about four times higher than the ratio for plantation area (7.72). It further strengthened the idea that the water at the secondary forest area was less polluted due to deforestation and changes of land use (Kleine and Trivinho-Strixino, 2005). In the secondary forest, there were more families of invertebrates which were exclusively found in the area as compared to plantation area. The order Coleoptera and Megaloptera were the two orders which had families of invertebrates there were exclusive to the secondary forest area, and there was no invertebrate which was exclusive to plantation area. This could probably due to the fact that they were more sensitive to their environment, and could survive better in clean water (Theischinger *et al.*, 1993).

The Shannon-Wiener Diversity Index (H') was calculated for the diversity of the aquatic invertebrates at different land uses, and the index obtained showed that the diversity of aquatic invertebrates at the secondary forest area was slightly higher than the plantation area with a value of 3.213 and 3.188 respectively. The number of family of invertebrates sampled in the secondary forest area (67 families) was also higher than the number of family sampled in plantation area (60 families). However, the Evenness Index calculated for different land uses only indicated a very small difference in index value. Plantation area had slightly higher evenness with an index value of 0.78, than the secondary forest area with an index value of 0.76. The lower evenness index in the secondary forest could be caused by the large number of Ephemeroptera and Coleoptera which had lowered the evenness of that area. The Shannon-Wiener Index value obtained for both the land uses exceeded 3.0 that had indicated that both of the habitats had a stable and balanced structure of habitat as the Shannon-Wiener Index value would generally range between 1.5 to 3.5, and rarely exceeded 4 (Magurran, 2005).

Aquatic invertebrates can be found in a wide variety of aquatic habitats, such as ponds, rivers, or streams which differed in salinity, pH, and other characteristics (Shayeghi *et al.*, 2014). From the aquatic invertebrates sampled, a relatively high number of individuals were obtained from riffle habitat, followed by leaf litter microhabitat, run and pool habitat (Table 3). A total of 1,119 individuals of aquatic invertebrates were captured from the riffle habitat which made up 31.27% of all the captured individuals. The microhabitat leaf litter appeared to be the second highest in terms of the number of individuals with a total of 964 individuals or 26.93%, and followed by the habitat run with 803 individuals or 22.44% of total captured individuals. The high number of individuals found from riffles habitat may be due to that the gravels and rocks at the riffle habitat created nooks and crannies on which the aquatic invertebrates were able to cling, or hide under it (Department of Natural Resources, 2008). In addition to that, the higher turbulence caused by the gravels in the riffle would also contribute to higher dissolved oxygen content which may make it a suitable site where the invertebrates congregated during the hotter time of the day (Michaud, 1994).

The diversity of aquatic invertebrates found in the riffle was, however, the lowest as compared to other habitats or microhabitats (H'=2.79) despite having the highest abundance, while the habitat which had the highest diversity index value was pool habitat. The high evenness of assemblages living in pool may had resulted in the higher diversity, whereas the heterogeneous environment of the riffle offered a greater number of niches, and reduced probability of predation creating higher abundance of the invertebrates (Principe, 2008). Similar abundance pattern had been seen by other authors, probably due to the difference in sedimentation by fine particulates in pool habitat (Baptista *et al.*, 2001). Aquatic invertebrates were also known to be highly correlated with the quantity of fine sediments. Sand deposition would lead to the increased abundance of a few aquatic invertebrate species, such as the mayflies, but the loss of other species (Arizona Department of Environmental Quality, 2015). Pool that had higher diversity and abundance of algae as compared to riffle habitat could contribute to the greater diversity as well (Mullner and Schagerl, 2003). Algae communities were important to provide energy to the aquatic invertebrates, and the rest of the food chain (Menninger and Palmer, 2007). The families found at the riffle habitat were lower as compared to other habitats and this might be due to the need for higher energy so as to avoid being displaced by the current, and in grazing for resources in that particular habitat (Principe, 2008).

Table 3: List of aquatic invertebrates collected from different habitats and microhabitats.

Order	Family	Habitats			Microhabitat
		Pool	Run	Riffle	Leaf Litter
Coleoptera	Dytiscidae	19	10	9	3
	Gyrinidae	13	6	5	15
	Chrysomelidae	15	3	33	16
	Psephenidae	7	12	14	14
	Elmidae	43	98	113	118
	Hydrophilidae	0	2	5	1
	Noteridae	3	0	5	2
	Limnichidae	2	0	0	0
	Dryopidae	59	15	9	0
	Curculionidae	0	0	1	0
	Eulichadidae	1	1	3	0
	Total	**162**	**147**	**197**	**169**
Diptera	Simulidae	15	34	47	58
	Culicidae	1	0	46	0
	Limaniidae	2	1	0	0
	Stratiomyidae	1	3	1	0
	Nauconidae	2	0	0	0
	Ceratopogonidae	11	1	6	6
	Chaoboridae	0	0	5	4
	Tabanidae	12	0	1	0
	Tipulidae	2	5	4	3
	Tanyderidae	1	0	1	5
	Thaumaleidae	13	0	0	1
	Chironomidae	17	61	41	20
	Empididae	0	0	0	1
	Ephydridae	0	1	0	0
	Nematocerapupa	0	1	0	0
	Sciomyzidae	0	0	0	1
	Total	**77**	**107**	**152**	**99**
Ephemeroptera	Ephemerellidae	51	58	78	71
	Leptophlebiidae	35	130	240	164
	Heptageniidae	25	33	44	47
	Behningiidae	3	10	28	34
	Tricorytidae	17	2	9	11
	Siphlonuridae	26	36	71	118

Baetidae	17	32	24	0
Caenidae	42	28	0	21
Potamanthidae	0	0	1	3
Oligoneuriidae	0	0	6	0
Neophemeridae	13	11	7	3
Total	**229**	**340**	**508**	**472**
Gerridae	22	15	7	18
Naucoridae	4	5	4	0
Herbridae	1	0	4	0
Pleidae	49	4	1	5
Hydrometridae	4	2	0	0
Belostomatidae	0	0	0	2
Veliidae	6	17	0	19
Corixidae	1	1	0	0
Mesoveliidae	1	1	0	0
Nepidae	4	0	0	0
Total	**92**	**45**	**16**	**44**
Corydalidae	3	7	28	10
Sialidae	0	3	0	0
Total	**3**	**10**	**28**	**10**
Aeshnidae	12	3	0	2
Gomphidae	34	7	2	4
Lestidae	11	1	9	10
Protoneuridae	7	3	0	1
Calopterygidae	1	1	0	0
Cordulegastridae	1	1	0	0
Coenagrionidae	0	7	4	6
Corduliidae	0	3	0	0
Libellulidae	1	1	0	0
Total	**67**	**27**	**15**	**23**
Capniidae	7	9	6	28
Chloroperlidae	7	8	15	25
Peltoperlidae	9	7	4	3
Perlodidae	0	2	0	1
Leuctridae	0	3	4	4
Perlidae	11	26	30	6
Pteronarcyidae	0	0	0	1
Total	**34**	**55**	**59**	**68**

Trichoptera	Psychomyiidae	0	18	8	31
	Hydropscyhidae	9	29	122	13
	Polycentropodidae	4	8	7	19
	Hydrascyhidae	3	3	0	0
	Hydroptilidae	7	5	3	9
	Glossosomatidae	4	6	3	2
	Brachycentridae	2	1	0	4
	Leptoceridae	0	2	0	0
	Limnephilidae	0	0	1	0
	Phryganeidae	0	0	0	1
	Total	**29**	**72**	**144**	**79**
Grand Total		**693**	**803**	**1119**	**964**

The diversity of the aquatic invertebrates was higher in the microhabitat of leaf litter than the riffle habitat. The higher diversity of invertebrates could be supported by the energy input from the leaves which were collected at the water, forming the habitat with higher energy content (Compson *et al.*, 2013). The Sørensen's Quantitative Index also showed that the species in both riffle habitat and microhabitat leaf litter had the highest similarity among all the other habitats. The lowest similarity was seen between the habitat pool and riffle with the index value of only 0.42, and the same was seen in another study on the assemblage of macroinvertebrates at different microhabitats (Bonada *et al.*, 2006). The leaf litter microhabitat was also the second to the riffle habitat in terms of abundance; both of these habitats had higher number of individuals that might be due to the shallow water depth, and the broken water surface that made the habitats suitable for hiding from predators from above the water surface (Principe, 2008).

Biotic indices were used to assess the condition of the water at Sg. Lipad. The indices included the EPT Richness, Family Biotic Index (FBI), Biological Monitoring Work Party (BMWP), and Average Score Per Taxon (ASPT). These biotic indices involved the use of macroinvertebrate survey to assess the health of the stream, and were commonly practiced by many researchers due to the little expertise or equipment needed (Barbour *et al.*, 1999). From the EPT Richness, Biological Monitoring Work Party, and Average Score Per Taxon calculated, both of the areas were classified into the same category of rather good quality water. Nevertheless, the index value for each of these indices was slightly higher in the secondary forest area with 25, 260, and 7.65 in EPT Richness, Biological Monitoring Work Party and Average Score Per Taxon respectively. However, the only difference was from the Family Biotic Index where the water in the secondary forest area had an index score of 4.15, which fell under the class of excellent quality, while the index score for plantation area was in the class of very good water with only 3.50 index score.

The EPT Richness measured for the different types of land use showed that the stream at both the plantation area and secondary forest area were non-impacted. The EPT Richness of both of the area was greater than 10, which was the cut-off value to be qualified as a non-impacted stream (Fikri, 2004). The EPT Richness for plantation was only one taxon lower than the secondary forest area. Nevertheless, the EPT Richness would be much more effective in reflecting the health of the stream if the invertebrates from the EPT communities were able to be identified until the species level (Che Salmah *et al.*, 2001).

The Family Biotic Index obtained for both the plantation area and secondary forest area were classed into different water quality groups. The plantation area was found to be more polluted than the secondary forest area in accordance to the FBI Index. The family Lestidae was more abundant in the plantation area, and with Nepidae occurred exclusively in plantation area, thus explained the higher index value for the plantation area as the family had a high tolerance towards pollution, and thus, the higher tolerance value. Conversely, Perlidae occurred exclusively in the secondary forest area indicated a cleaner water quality as they were rather intolerant towards pollutants in the water. Nevertheless, the plantation area was considered as having water with very good quality, while the water quality in the secondary forest area was excellent. This lower water quality of the plantation area could be due to the water run-off from the oil palm plantation that was contaminated with pesticides or enriched with much nutrients from fertilizers utilized in the agricultural activities (Adusumilli *et al.*, 2011). FBI uses both richness and abundance in its analysis, making it weighted towards the most abundant taxa (Goldstein, 2011). Recent studies showed that with the use of more than 20 organisms, it was possible for FBI to generate accurate results (Mandaville, 2002).

The Biological Monitoring Work Party measured for both the areas showed that they were both considered as having good quality water. The secondary forest area had a higher index value as compared to the plantation area. BMWP uses the tolerance of certain families of invertebrates by giving them scores at a scale of 1 to 10, and thus, summing into the BMWP index value (Zeybek *et al.,* 2014) . Due to the reliance on the number of taxa found in the measurement of the index, the difference in sampling intensity may result in wrong assumption on the water quality by depending solely on this index alone (Roche *et al.*, 2010). Therefore, the index ASPT was also included in the study as well. ASPT included the number of families found into consideration, and divided the total BMWP with the total number of families used to calculate BMWP (Roche, 2010). The ASPT score of plantation area was only slightly lower than the score for the secondary forest area. They were both classed into the group of 'Rather Clean Water', which was the second highest class in terms of water cleanliness. Nonetheless, the scores of both areas were rather high, and were rather near to the range of 'Very Clean Water'. This, again similar to the other indices, gave a signal that the water quality at both the plantation and secondary forest area were rather clean.

In addition to the biotic indices that were used in this study, the physico-chemical parameters were also recorded during the sampling process (Table 4). Several physical water quality parameters, such as pH, temperature, conductivity, and dissolved oxygen were measured and compared according to the Interim National Quality Water Standards for

Malaysia (INQWS). The pH for both plantation area and the secondary forest area only differed by 0.2 where plantation area was slightly more acidic as compared to the secondary forest area. However, both of these areas were classed into having Class I water under the INQWS. Similarly, the conductivity of both areas was also classified as having Class I water. The dissolved oxygen for both plantation area and the secondary forest area were classed under Class IIA, whereby the water was still clean and could be used after the conventional treatment of water. The obtained water quality parameters indicated that the water at Sg. Lipad was of rather clean water, which was in consistent with the biotic indices calculated. This showed that the close relationship between the aquatic invertebrate communities and the water quality, allowed them to be used effectively for rapid water quality assessment.

Table 4: Mean values of the water quality parameters at different stations at Sg. Lipad with Interim Water Quality Standards for Malaysia (INWQS).

Parameters	Station	Mean Values	INWQS	Class
Dissolved Oxygen	Plantation	5.71	5-7	IIA
	Secondary	5.67	5-7	IIA
pH	Plantation	7.71	6.5-8.5	I
	Secondary	7.98	6.5-8.5	I
Temperature	Plantation	26.42	Normal	-
	Secondary	25.02	Normal	-
Conductivity	Plantation	110	1000	I
	Secondary	167.25	1000	I

CONCLUSIONS

The highest abundance of aquatic invertebrates was for Ephemeroptera, while the least was for the order Megaloptera. From the two different land uses where samplings were done, the abundance of the invertebrates collected in the secondary forest area were much higher than plantation area, except for the order Diptera. This could be due to the polluted water at plantation area which Diptera were tolerated to. The diversity of the secondary forest area was slightly higher than the plantation area. This could be due to the high evenness of the invertebrate assemblages in the plantation area or the invertebrates had become adapted to the polluted water in becoming a much stable community as compared to the previous study conducted 10 years ago. Therefore, further studies are being proposed with longer time duration in order to obtain a larger number of samples, and to cover more habitats so that the notion that the community is becoming stable can be strengthened.

The comparison between the different habitats and microhabitats samples suggested that there was a relatively higher abundance of aquatic invertebrates in riffle habitat, while the least number of individuals was found in the pool habitat. Riffle habitat is a heterogeneous environment which offers a great number of niches for the invertebrates, and it has more turbulence of which contributes to the constant high input of oxygen into the water to increase the dissolved oxygen content of water at that habitat.

Biotic indices were used in this study to assess the water quality of the stream with the use of aquatic invertebrates. From all biotic indices calculated, except for the Family Biotic Index, the water quality of both areas was classified as the highest on the scale in terms of cleanliness. It indicated that the water quality at both plantation and the secondary forest area was rather clean with the water quality at the secondary forest area slightly cleaner than plantation area. Nonetheless, the water quality for plantation area, according to the FBI, showed that it was of only very good quality, while the water at the secondary forest area was of excellent quality. These biotic indices were compared to the physico-chemical parameters measured for the stream at both land uses. The water quality of both areas was classified at Class I in terms of the pH, temperature, and conductivity, which was in coherence with the assessment derived from the biotic indices. This thus showed the potential use of aquatic invertebrate communities in rapid assessment of stream water quality as a faster and cheaper way.

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