Diversity of aquatic macroinvertebrate assemblages and their functional feeding groups in the streams of Kota Marudu, Sabah

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Abstract. Increasing human activities at Kota Marudu (an economic and agricultural hub of northern Sabah) affects water quality and related ecosystem services. However, the impacts of these human activities on the aquatic biological assemblages in tropical streams were poorly understood. Thus, the objective of this study was to determine the biological diversity and functional feeding groups of aquatic macroinvertebrate assemblages of some streams near different types of land use. Water samples and aquatic macroinvertebrates were collected from 6 streams, in 6 sampling trips. A total of 22994 individuals were identified with 136 genera and 17 orders corresponding to 3 main faunal phyla (Annelida, Mollusca, Arthropoda). Biodiversity indices and biotic indices showed significant spatial differentiation. The biodiversity of aquatic macroinvertebrate assemblages was highest at forested streams and lowest at streams from agricultural lands. In addition, the functional feeding groups also showed significant differences between the forested streams and human-disturbed rivers. Shredders and predators were more abundant in forested streams. In general, land use is an important factor influencing the structure of aquatic communities.

Key Words: biological diversity, land use, macrobenthos, tropical streams.

Introduction. Aquatic macroinvertebrate assemblages are diverse and ubiquitous in water bodies (Barbour et al 1999). As key inhabitants of aquatic ecosystems, aquatic macroinvertebrate assemblages link the benthic and pelagic food networks (Palmer et al 2000; Cai et al 2011). Moreover, aquatic macroinvertebrate assemblages and stream water quality are complementary (Mahazar et al 2013; Barman & Gupta 2015; Prommi & Payakka 2015). Therefore, understanding the effects of anthropogenic stressors on aquatic macroinvertebrate assemblages is essential for an effective impact assessment of watercourses (Carter et al 2006).

Aquatic biodiversity is one of the most important characteristics in maintaining the stability of aquatic ecosystems (Vinson & Hawkins 1998; Sharma et al 2004; Gupta & Narzary 2013). Also, the biodiversity data are crucial and needed to develop viable conservation and management strategies. Meanwhile, the functional feeding strategies provide information regarding the complementarity and redundancy of co-occurring species, while indicating the ecosystem productivity and susceptibility (Talaga et al 2017). Therefore, ecological knowledge of aquatic macroinvertebrates is vital in deducing the stability and productivity of aquatic ecosystems. The response of aquatic macroinvertebrates to various disturbances is effective tool in the conservation of aquatic fauna (Larsen & Ormerod 2010; Md Rawi et al 2013).

Tropical streams are found in tropical regions (Boyero et al 2009). Biodiversity studies at tropical watersheds in Southeast Asia are insufficient (Al-Shami et al 2017; Ng et al 2017). Furthermore, the incomplete taxonomic information of freshwater macroinvertebrate assemblages impedes ecological research in Southeast Asia (Yule & Yong 2004).

The rapid development of commercial sectors in Kota Marudu makes it the economical and agricultural center of northern Sabah. Forest and land clearing for agricultural and urbanization activities affects the streams Kota Marudu in many ways. Agriculture and urban development are altering the hydrological regimes and creating impermeable areas, which leads to an increased runoff of sediments, nutrients and other pollutants (Allan et al 1997; Nessimian et al 2008; Narangarvuu et al 2014). Therefore, this study aims to improve the knowledge gaps on the biological diversity of freshwater macroinvertebrates and their functional feeding groups in streams near different types of land uses in the tropical region.

Material and Method

Description of the study sites. The study area was in Kota Marudu ($6^0$29'13.79"N, $116^0$44'5.99"E), Sabah, situated at the southern end of Marudu Bay (Figure 1). 6 streams, namely Serinsim stream (SS), Kinarom stream (KS), Batutai stream (BAS), Bingkongan stream (BIS), Lugu stream (LS), and Mengaris stream (MS) were selected for this study. The rivers were chosen based on land use types: SS and KS were classified as forested streams, both located inside the protected Kinabalu Park; LS and MS were classified as rural streams, while BAS and BIS as agricultural streams.

Physico-chemical parameters analyses. The samplings were conducted in 6 sampling occasions: July 2017, August 2017, September 2017, October 2017, February 2018, and March 2018. Three substations were set up along 150 m of each stream reach. The *in-situ* parameters, including pH, dissolved oxygen (DO), conductivity, temperature, salinity, total dissolved solids (TDS), were measured with YSI Professional Plus (ProPlus) (Model 6026 S/N Y 5173). The probe of the YSI Proplus was positioned in the center of the stream and readings were recorded when it was stabilized (Harun et al 2010). Three replicates of readings were recorded for each stream. To analyze the nitrate and phosphate concentration in the stream, three water samples were collected at every sampling site and stored in 250 mL high-density-polyethene (HDPE) containers. The containers were pre-rinsed with 10% hydrochloric acid (HCl) and washed with distilled water (Harun et al 2014). Before collecting the water samples, the HDPE bottles were rinsed three times with the stream water (Perera et al 2016; Tan et al 2017). All water samples were wrapped with black plastic bags and transported back to the guesthouse in an ice filled Coolman® ice container. The nitrate and phosphate were analyzed using the DR900 Multiparameter Portable Colorimeter (HACH 2013), the same day the water samples were collected.

Aquatic macroinvertebrates sampling. Five types of habitats/microhabitats were identified and sampled at each substation: pool, riffles, run, gravel (grain size: 1-6.5 cm) and riparian vegetation. The riparian vegetation is designated at a five-meter wide zone on both sides of the sampling station (Sandin 2003). Therefore, a total of 15 subsamples were collected from each stream. The Surber sampler (500 µm mesh size, rectangular quadrat of 30x30 cm) was used due to its capability to retain more rare taxa (Wan Abdul Ghani et al 2016). Each subsample was collected in 2 minutes. The Surber sampler was positioned with the opening facing upstream (Jalil & Mohamed 2004). All larger rock surfaces within the Surber sampler quadrat were lifted and the attached aquatic macroinvertebrates were scrapped off into the net. Then, the remaining substrate was agitated and the dislodged materials floated into the net (Jalil & Mohamed 2004). The subsamples were placed in white enamel pans for screening and sorting. Sorted macroinvertebrates were stored in properly-labelled universal containers (with 90% ethanol) and transported back to the laboratory for identification.

The collected aquatic macroinvertebrates were identified to the genus level using the keys following Morse et al (1994), Yule & Yong (2004), Sangpradub & Boonsoong (2006), Merritt et al (2008), Webb & Mccafferty (2008) and Polhemus et al (2008). However, some were identified to higher taxonomic levels (e.g. Oligochaeta, Lycosidae, Isotomidae and Chironomidae), due to the lack of taxonomic keys. Expert opinions for Coleoptera were obtained from Dr. Hendrik Freitag (personal communication) and for Mollusca from Mr. Foon Junn Kitt (personal communication). The 5 functional feeding groups (FFGs) were classified according to trophic relation (Morse et al 1994; Merritt et al

2008; Yule et al 2009). The feeding strategies of the FFGs are the following (Ramírez & Gutiérrez-Fonseca 2014): shredders (SHR) cut and chew large particles of plant material; collector-gatherers (GLG) sieve small particles accumulated beneath the stream with modified mouth parts; collector-filterers (CFL) capture small particles in the water column, either through modified mouth parts or net construction; predators (PRD) prey on other organisms; scrapers (SCP) consume the biofilm or algae attached to the substrate.

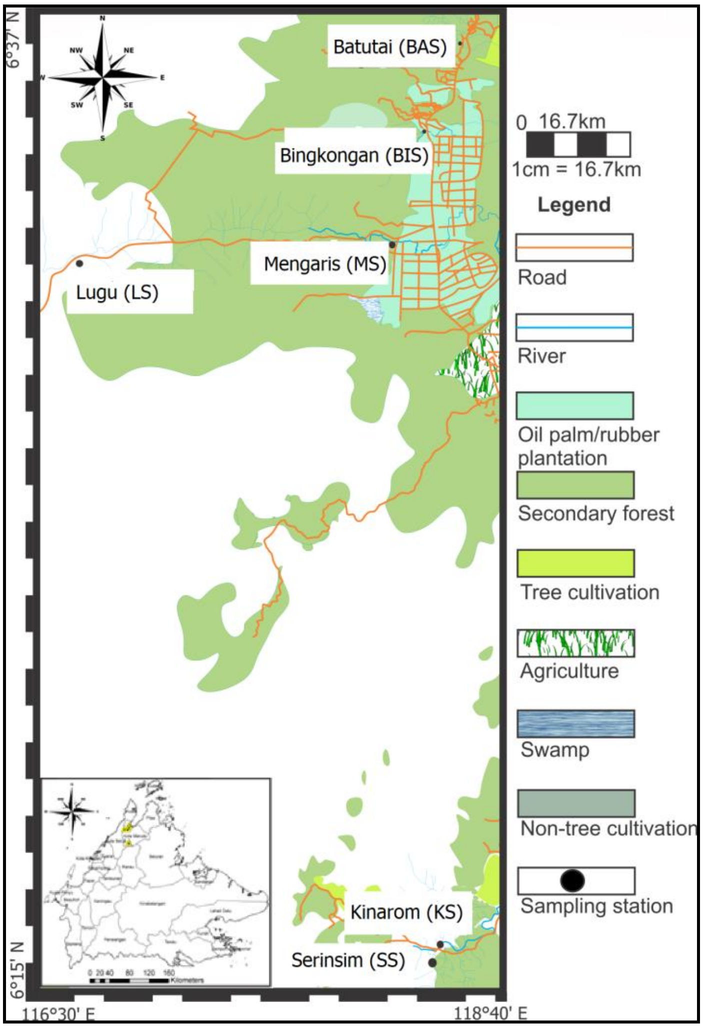

Figure 1. Locations of the 6 streams namely the Serinsim, Kinarom, Batutai, Bingkongan, Lugu, and Mengaris in Kota Marudu.

***Statistical analysis**.* The Shannon-Weiner index (H'), Pielou's evenness index (J') Simpson index (D) and rarefied richness of aquatic macroinvertebrates were computed using the vegan package (version 2.5.2) of the statistical program R (version 3.5.0) (R Core Team 2018). To standardize the sample size differences across the streams, the observed genus richness was rarified. A cut-off rate for the inclusion in taxon richness analysis was based on the lowest number of individuals from a sample (338 individuals). This is also the sufficient number of individuals (approximately 300 individuals) in fixed count studies for taxon richness comparison (Vinson & Hawkins 1996; Sandin 2003). The three biotic indices: Ephemeroptera, Plecoptera, Trichoptera (EPT family richness) index, Thailand version of Biological Monitoring Work Party ($BMWP^{THAI}$), and Average Score Per Taxon ($ASPT^{THAI}$) were used for the water quality assessment. There are five water quality classes ($BMWP^{THAI}$ and $ASPT^{THAI}$), including: very good (>130; >7), good (81-130;

6.0-6.9), moderate (51-80; 5.0-5.9), poor (11-50; 4.0-4.9), and bad (0-10; <3.9) (Hoang 2009).

Therefore, One-way analysis of variance (ANOVA) was used to examine the differences between aquatic macroinvertebrate metrics among the 6 sampled streams. The analysis was performed with the statistical program R version 3.5.0 (R Core Team 2018).

Results and Discussion

Physico-chemical parameters. The physicochemical parameters showed degradation in a forest-rural-agricultural gradient (Table 1). Forested streams (KS and SS) recorded relatively lower water temperature but higher pH, conductivity, TDS, and salinity when compared with those of other human-disturbed streams. The pH of forested streams was slightly more alkaline (KS - 8.27; SS - 8.26), while the agricultural stream (BIS) recorded the highest temperature, 28.97^{0}C. Meanwhile, another agricultural stream (BAS) had the highest nitrate value recorded (3.41 mg L^{-1}) but had the lowest value of conductivity (77.21 µS cm^{-1}), pH (7.21), TDS (47.18 mg L^{-1}), and salinity (0.03 ppt).

Table 1

Pphysicochemical parameters across the six streams of Kota Marudu

Parameters	*Forest streams*		*Rural streams*		*Agriculture streams*	
	Kinarom	*Serinsim*	*Lugu*	*Mengaris*	*Batutai*	*Bingkongan*
pH	8.27	8.26	7.62	8.12	7.21	7.44
Temperature (ºC)	22.56	23.38	25.22	26.89	26.19	28.97
Conductivity (µS cm^{-1})	162.26	134.66	109.13	166.53	77.21	130.76
Dissolved oxygen (mg L^{-1})	8.79	8.72	8.02	8.34	8.41	7.22
Salinity (ppt)	0.08	0.07	0.05	0.08	0.03	0.06
Total dissolved solids (mg L^{-1})	103.38	86.62	67.11	98.49	47.18	79.15
Nitrate (mg L^{-1})	0.58	0.49	1.78	1.33	3.41	0.91
Phosphate (mg L^{-1})	0.17	0.25	0.34	0.19	0.33	0.17

Aquatic macroinvertebrates. Aquatic macroinvertebrates were comprised of 22994 individuals from 17 orders and 136 genera (Tables 2 and 3). Most of the collected taxa were insects (125 taxa) and accounted for 94.36% of the total samples. The predominant macroinvertebrate group was Ephemeroptera, with 9 families, 22 genera and 9766 individuals (42.47%). The rarest taxonomic groups were Blattaria and Collembola, each with only one individual collected. For non-insects, the Mollusca individuals (3%) had the highest contribution to the overall collected aquatic macroinvertebrates. Other non-insect include crustaceans, arachnids and annelids.

Rarefaction curves substantiated a higher aquatic macroinvertebrate diversity in forest streams (KS and SS) (Figure 2). Meanwhile, the lowest genera richness was recorded in agricultural streams (SBI and SBA). The rural stream (LS) recorded the highest order richness with 17 orders, while the lowest order richness was observed at the agricultural stream (BAS) (Table 2). For family richness, forested stream (KS) had the highest richness among the 6 streams. Total genus richness of aquatic macroinvertebrates declined in a forest-rural-agricultural gradient. The total number of individuals was highly variable among the land use types. The highest value was found in the rural stream (MS - 5418 individuals), followed by the agricultural stream (BAS - 4200 individuals) and forest stream (SS- 3645 individuals).

All datasets were normally distributed when tested with the Kolmogorov-Smirnov test (P>0.05). The data did not fulfil the homogeneity of variance (Levene's tests) requirement were log10 (x+1) transformed. The macroinvertebrate metrics tested with ANOVA were listed in Table 2, and the remaining tested metrics were the proportion of each FFG. There were significant differences among sampling streams in the diversity indices ($P<0.001$) and abundance ($F=2.928$, $P=0.0287$). The Shannon-Weiner index was highest for the forested streams (3.15 and 3.21), whereas the lowest value occurred at one of the agricultural streams (SBI). In addition, the Simpson index values were uniformly high (0.85-0.93; with a possible range of 0-1). Pielou's evenness index was similar for both forested streams, while the lowest value was observed in the rural stream (LS). The highest mean abundance per m^2 was found in the rural stream (SM) (10033.33±274.95), and the lowest in the agricultural stream (BIS) (5581.44±135.35).

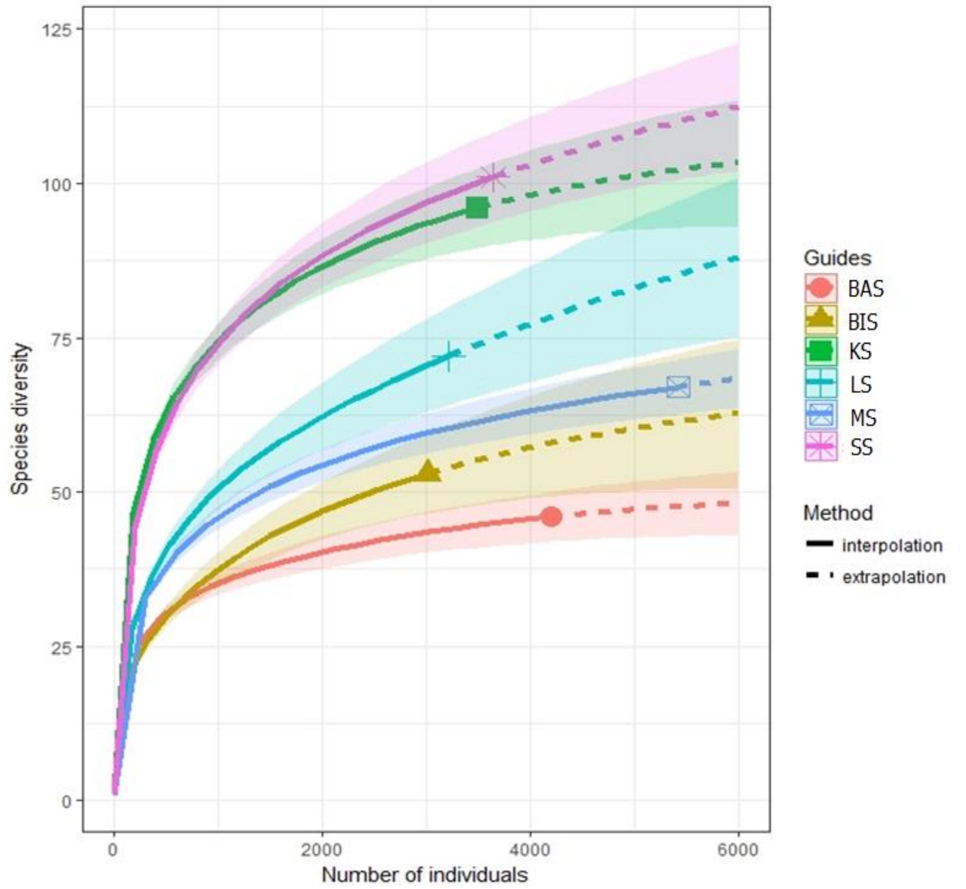

Figure 2. Comparison of the rarerified richness of aquatic macroinvertebrate assemblages among the 6 streams: Serinsim (SS), Kinarom (KS), Batutai (BAS), Bingkongan (BIS), Lugu (LS), and Mengaris (MS).

Lastly, the rarefied richness was highest in the forest streams. Most of the aquatic macroinvertebrates collected at the rural streams belonged to the EPT groups (82.19 to 77.91%). The forest stream (KS) had relatively higher family richness, BMWP$^{\text{THAI}}$ score, and ASPT$^{\text{THAI}}$ scores when compared to those of other streams. Also, the EPT index was higher in forest streams, being indicative of a better water quality. In contrast, agricultural streams had a lower BMWP$^{\text{THAI}}$ score, family richness and EPT index. For ASPT$^{\text{THAI}}$ index, rural and agricultural streams had fair water quality, in contrast to the better water quality rating (good) of forested streams.

Table 2

Aquatic macroinvertebrate metrics of aquatic macroinvertebrates in the sampled six streams at Kota Marudu

Metrics	*Forest streams*		*Rural streams*		*Agricultural streams*		*ANOVA*
	SK	*SS*	*SL*	*SM*	*SBA*	*SBI*	
Total no. of orders	14	14	17	16	11	14	-
Total no. of families	58	57	45	45	30	36	-
Total no. of genera	93	98	71	66	45	52	
Total no. of individuals	3499	3645	3218	5418	4200	3014	-
Shannon-Weiner Index (H’)	3.21±0.23	3.15±0.21	2.38±0.08	2.64±0.11	2.39±0.19	2.31±0.14	29.45**
Simpson Index (D)	0.93±0.02	0.93±0.03	0.81±0.03	0.89±0.01	0.86±0.03	0.85±0.04	14.57**
Pielou’s evenness Index (J’)	0.79±0.05	0.78±0.04	0.65±0.02	0.73±0.03	0.72±0.05	0.71±0.05	7.96**
Rarefied Richness	49.48±4.19	48.63±6.05	34.44±2.51	29.93±2.04	23.73±3.44	23.24±2.87	58.39**
Genera Richness	58.17±8.59	56±5.97	40±4.93	38.17±2.34	27.83±3.18	26±2.58	35.64**
Abundance/m^2	6479.66±171.37	6750±197.74	6070.33±137.37	10033.33±274.95	7777.77±182.91	5581.44±135.35	2.93*
% EPT	66.96	71.28	82.19	77.91	58.14	75.65	-
No. of families	38±6.66	33.83±2.93	28±3.41	27.5±2.59	20.67±2.16	20±2.68	21.83**
EPT index	14.33±2.58 (Very good)	13.17±1.33 (Very good)	10.5±1.76 (Very good)	10.67±1.51 (Very good)	8.17±0.41 (Good)	7.33±1.03 (Good)	17.76**
$\text{BMWP}^{\text{Thai}}$	200.5±28.28 (Very good)	189±16.95 (Very good)	144.33±11.52 (Good)	149.17±13.76 (Good)	118.5±11.22 (Good)	115±12.03 (Good)	26.89**
$\text{ASPT}^{\text{Thai}}$	6.61±0.15 (Good)	6.6±0.19 (Good)	6.12±0.26 (Fair)	6.31±0.1 (Fair)	6.42±0.26 (Fair)	6.33±0.2 (Fair)	5.15*

Note: * - P<0.05; ** - P<0.01; % EPT - percentage of Ephemeroptera, Plecoptera and Trichoptera; $\text{BMWP}^{\text{THAI}}$ - Thailand version of the Biological Monitoring Work Party; $\text{ASPT}^{\text{THAI}}$ - Thailand version of the Average Score per Taxa. SS - Serinsim; KS - Kinarom; BAS - Batutai; BIS - Bingkongan; LS - Lugu; MS - Mengaris.

Table 3

Aquatic macroinvertebrate composition in the six streams

Taxa	*FFG*	*Forest streams*		*Rural streams*		*Agriculture streams*	
		KS	*SS*	*LS*	*MS*	*BAS*	*BIS*
			INSECTS				
EPHEMEROPTERA							
Baetidae							
Acentrella	CLG	380	397	91	256	65	304
Baetiella	CLG	17	12	1	27	0	0
Baetis	CLG	237	328	195	187	147	729
Gratia	CLG	2	11	3	29	3	0
Platybaetis	CLG	122	205	49	500	36	26
Caenidae							
Caenodes	CLG	33	62	164	101	154	35
Ephemerellidae							
Crinitella	CLG	23	62	5	87	1	47
Torleya	CLG	25	28	0	9	0	0
Euthyplociidae							
Polyplocia	CLG	34	1	10	4	0	0
Heptageniidae							
Asionurus	CLG	4	12	14	12	1	3
Atopopus	CLG	0	0	3	1	2	0
Campsoneuria	CLG	16	1	2	0	6	5
Cinygmina	CLG	62	189	164	661	399	188
Ecdyonurus	CLG	9	11	7	14	14	2
Epeorus	CLG	2	6	0	0	0	0
Isonychiidae							
Isonychia	CFL	1	4	4	0	0	0
Leptophlebiidae							
Choroterpes	CLG	67	134	415	812	645	230
Habrophlebiodes	SCP	1	5	13	0	16	0
Isca	CLG	3	3	1	4	0	0
Thauralus	CLG	0	0	2	0	0	0
Potamanthidae							
Potamanthus	CFL	56	65	0	0	0	0
Teloganodidae							
Teloganodes	CLG	47	30	77	45	30	2
TRICHOPTERA							
Calamoceratidae							
Anisocentropus	SHR	0	1	0	0	0	0
Ecnomidae							
Ecnomus	CFL	1	2	19	1	0	0
Helicopsychidae							
Helicopsyche	SCP	0	1	0	0	0	0
Hydropsychidae							
Cheumatopsyche	CFL	285	296	1295	996	342	317
Hydropsyche	CFl	399	289	56	139	125	9
Macrostemum	CFL	2	0	5	2	266	157
Lepidostomatidae							
Lepidostoma	SHR	3	0	0	0	0	0
Leptoceridae							
Setodes	CLG	0	4	0	0	0	0
Triaenodes	SHR	2	2	0	0	1	0
Philopotamidae							
Chimarra	CFL	7	9	6	104	148	0
Wormaldia	CFL	2	1	3	0	1	0
Polycentropodidae							
Polyplectropus	PRD	2	5	4	12	36	1
Psychomyiidae							
Psychomyia	CFL	11	11	1	3	0	0

Table 3

Aquatic macroinvertebrate composition in the six streams (continuation)

Taxa	*FFG*	*Forest streams*		*Rural streams*		*Agriculture streams*	
		KS	*SS*	*LS*	*MS*	*BAS*	*BIS*
				INSECTS			
COLEOPTERA							
Dryopidae							
Elmomorphus	SCP	118	113	8	17	2	1
Dytiscidae							
Hydrovatus	PRD	0	0	2	0	0	0
Rhantus	PRD	0	1	0	0	0	0
- (larvae)	PRD	0	2	0	0	0	0
Elmidae							
Dryopomorphus (larvae)	SCP	15	6	0	0	0	0
Dryopomorphus (adult)	SHR	1	4	0	0	0	0
Grouvellinus (adult)	SHR	4	1	0	0	0	0
Homalosolus	SHR	0	3	0	0	0	0
Potamophilus (larvae)	CLG	20	17	4	2	0	0
Potamophilus (adult)	CLG	0	2	0	0	0	1
Stenelmis (larvae)	SCP	34	50	7	45	16	3
Stenelmis (adult)	SCP	25	62	73	52	102	5
- (larvae)	SCP	9	9	0	0	0	0
Haliplidae							
Haliplus	SHR	0	0	0	2	0	0
Eulichadidae							
Eulichas	PRD	30	11	0	0	0	1
Gyrinidae							
Gyrinus	PRD	4	14	0	4	0	1
Orectochilus	SHR	0	1	0	0	0	0
Hydrophilidae							
Berosus	CLG						
Laccobius	CLG						
Lampyridae	PRD	13	11	2	0	0	0
Psephenidae							
Jaechanax	SCP	4	3	0	0	0	0
Jinbrianax	SCP	71	28	1	0	0	0
Macroeubria	SCP	1	0	0	0	0	0
Microeubria	SCP	4	2	0	0	0	0
Mubrianax	SCP	42	9	0	0	0	0
Odontanax	SCP	24	53	56	113	1051	18
Psephenoides	SCP	38	11	7	32	0	0
Scirtidae	CFL	27	12	27	8	8	1
DIPTERA							
Blephariceridae							
Blepharicera	SCP	36	22	0	0	0	0
Ceratopogonidae							
Forcipomyia	PRD	1	0	0	0	0	0
Chironomidae	PRD	39	73	9	14	22	12
Deuterophlebiidae							
Deuterophlebia	SCP	1	1	0	0	0	0
Ephydridae	CLG	1	0	0	0	0	0
Sciomyzidae	PRD	0	0	0	2	0	0
Simuliidae							
Simulium	CFL	127	91	97	274	241	174
Syrphidae	CLG	0	0	0	0	1	0
Tabanidae	PRD	3	2	0	1	0	0
Tipulidae							
Hexatoma	PRD	23	20	27	25	5	13
Leptotarsus	SHR	3	5	1	1	0	0
Tipula	SHR	19	20	18	9	6	3

Table 3

Aquatic macroinvertebrate composition in the six streams (continuation)

Taxa	*FFG*	*Forest streams*		*Rural streams*		*Agriculture streams*	
		KS	*SS*	*LS*	*MS*	*BAS*	*BIS*
INSECTS							
PLECOPTERA							
Leuctricidae							
Rhopalopsole	SHR	2	1	2	0	0	0
Nemouridae							
Amphinemura	SHR	7	1	1	0	0	0
Nemoura	SHR	4	0	0	0	0	0
Peltoperlidae							
Peltoperlopsis	SHR	85	7	1	0	0	0
Perlidae							
Etrocorema	PRD	45	33	0	1	0	0
Neoperla	PRD	274	292	31	214	4	225
Phanoperla	PRD	47	37	0	0	0	0
Tetropina	PRD	24	40	1	0	0	0
HEMIPTERA							
Aphelocheiridae							
Aphelocheirus	PRD	126	102	0	0	0	0
Gerridae							
Amemboa	PRD	0	1	1	3	2	0
Cylindrostethus	PRD	0	0	0	0	1	0
Metrocoris	PRD	4	4	1	3	15	2
Pleciobates	PRD	0	1	0	0	0	0
Potamometropsis	PRD	0	0	1	0	0	0
Rhagodotarsus	PRD	0	0	1	0	0	1
Rheumatogonus	PRD	0	1	0	0	0	0
Helotrephidae							
Hydrotrephes	PRD	4	0	0	0	0	0
Helotrephes	PRD	1	1	2	5	0	1
Hydrometridae							
Hydrometra	PRD	0	0	1	0	0	0
Mesoveliidae							
Mesovelia	PRD	0	1	1	0	0	0
Naucoridae							
Coptocatus	PRD	46	45	0	0	0	0
Laccocoris	PRD	11	20	0	0	0	0
Nepidae							
Cercotmetus	PRD	0	0	0	1	0	0
Ranatra	PRD	1	0	0	0	0	0
Veliidae							
Rhagovelia	PRD	23	3	23	2	3	1
ODONATA							
Calopterygidae							
Calopteryx	PRD	0	2	0	0	0	1
Vestalis	PRD	4	4	0	0	0	0
Coenagrionidae							
Pseudagrion	PRD	0	0	1	1	15	25
Cordulegastridae							
Cordulegaster	PRD	1	0	0	0	0	0
Euphaeidae							
Euphaea	PRD	6	6	90	90	31	5
Gomphidae							
Acrogomphus	PRD	0	3	0	1	0	2
Heliogomphus	PRD	0	1	0	0	0	0
Microgomphus	PRD	0	3	0	0	0	0
Nepogomphus	PRD	6	4	0	1	0	1
Paragomphus	PRD	1	0	0	0	0	0
Phaenandrogomphus	PRD	8	0	0	1	0	0
Sieboldius	PRD	0	2	0	0	0	0
Stylogomphus	PRD	0	0	0	0	0	1

Table 3

Aquatic macroinvertebrate composition in the six streams (continuation)

Taxa	*FFG*	*Forest streams*		*Rural streams*		*Agriculture streams*	
		KS	*SS*	*LS*	*MS*	*BAS*	*BIS*
			INSECTS				
ODONATA							
Libellulidae							
Cratilla	PRD	0	0	0	0	0	2
Onychothemis	PRD	2	0	0	0	0	4
Zygonyx	PRD	2	1	0	0	0	0
Zyxomma	PRD	0	0	0	0	0	1
Macromiidae							
Macromia	PRD	0	3	0	0	0	0
Platycnemididae							
Copera	PRD	0	0	0	0	2	0
Platystictidae							
Drepanosticta	PRD	2	1	0	1	0	0
MEGALOPTERA							
Corydalidae							
Protohermes	PRD	65	55	24	3	0	0
LEPIDOPTERA							
Crambidae							
Elophila	SHR	1	1	0	0	0	0
Noctuidae							
Spodoptera	SHR	1	0	0	1	0	1
Pyralidae							
Parapoynx	SHR	29	34	1	5	0	3
BLATTARIA							
Blattidae	SHR	0	0	1	0	0	0
			NON-INSECTS				
DECAPODA							
Atyidae							
Caridina	CLG	0	0	1	10	119	103
Palaemonidae							
Macrobrachium	CLG	2	3	30	11	18	72
Potamidae							
Isolapotamon	CLG	9	8	21	12	70	2
ISOPODA							
Cirolanidae							
Anopsilana	PRD	1	1	0	3	1	0
ARACHNEAE							
Lycosidae	PRD	0	3	1	3	0	2
TROMBIDIFORMES							
Arrenuridae							
Arrenurus	PRD	0	0	1	1	0	0
COLLEMBOLA							
Isotomidae	CLG	1	0	0	0	0	0

Table 3

Aquatic macroinvertebrate composition in the six streams (continuation)

Taxa	*FFG*	*Forest streams*		*Rural streams*		*Agriculture streams*	
		KS	*SS*	*LS*	*MS*	*BAS*	*BIS*
			INSECTS				
MOLLUSCA							
Thiaridae							
Melanoides	SCP	0	0	1	58	2	14
Tarebia	SCP	0	0	4	208	2	238
Thiara	SCP	0	0	0	0	0	1
Nassariidae							
Clea	SCP	18	1	1	0	0	0
Pachychilidae							
Sulcospira	SCP	19	23	14	132	23	3
Cyrenidae							
Corbicula	SCP	0	0	0	0	0	3
ANNELIDA							
Lumbricidae	CLG	0	0	5	7	0	12

Note: SS - Serinsim; KS - Kinarom; BAS - Batutai; BIS - Bingkongan; LS - Lugu; MS - Mengaris; SHR - shredders; CLG - collector-gatherers; CFL - collector-filterers; PRD - predators; SCP - scrapers.

Functional feeding groups (FFGs). Among the aquatic macroinvertebrates collected, there were 57 predator taxa, 31 collector-gatherer taxa, 22 scraper taxa, 18 shredder taxa, and 11 collector-filterer taxa (Figure 3). The collector-gatherers, as the main functional feeding group (45.89%), contributed to nearly half of the individuals sampled (Figure 3). Second dominant FFG was collector-filterers (27.19%), followed by scrapers (13.92%) and predators (11.28%). Shredders exhibit the lowest abundances (1.72%) in all six streams. Collector-gatherers were the dominant FFG that occurred at most streams. Although the rural stream (SL) was dominated by collector-filterers, both forested streams had higher abundance of shredders (5.46% and 4.01%) and predators (22.55% and 20.41%), in comparison with the rural and agricultural streams. Interestingly, the relative abundance of scrapers in the agricultural stream (SBA) was the highest among the 6 streams. The proportions of each FFG differed significantly between the streams, as showed by the ANOVA results (predators: F=7.8153, P=0.000; shredders: F=21.457, P=0.000; scrapers: F=5.6096, P=0.001; collector-gatherers: F=4.0585, P=0.006; collector-filterers: F=3.6874, P=0.01).

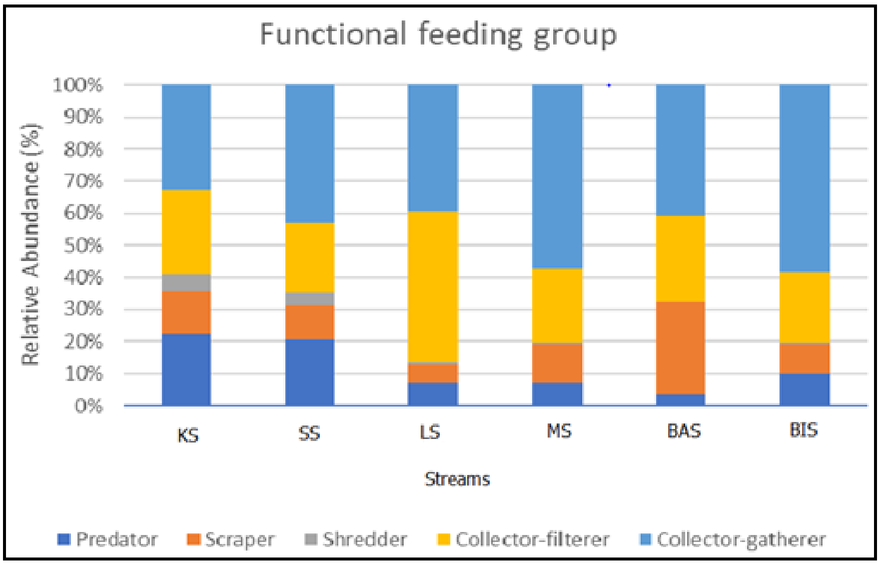

Figure 3. Composition of the functional feeding groups of aquatic macroinvertebrates in the 6 streams: Serinsim (SS), Kinarom (KS), Batutai (BAS), Bingkongan (BIS), Lugu (LS), and Mengaris (MS).

Ephemeroptera, Plecoptera and Trichoptera (EPT) assemblages are typically perceived as organismal bioindicators of water quality among the freshwater macroinvertebrate assemblages. The percentage of EPT (58.14% to 82.19%) does not show striking variation among the 6 streams. Rural streams, SL and SM, composed the highest percentage of the EPT assemblage. This finding contradicted the results of other studies (Azrina et al 2006; Wahizatul et al 2011; Al-Shami et al 2017), where EPT was highly abundant in the nonimpacted area. The high abundance of EPT in the impacted streams was mainly due to the existence of tolerant taxa: *Baetis*, *Cheumatopsyche*, and *Choroterpes*.

A noteworthy observation was the restriction of the rare water mite, *Arrenurus*, in the rural streams (LS and MS). Genus *Arrenurus* was reported as a parasite of Diptera and Odonata (Zawal 2004). Therefore, the presence of *Arrenurus* may be the result of the abundance of Diptera and Odonata nymphs. In addition, Decapoda and Mollusca showed higher dominance in the agricultural streams. The bivalve *Corbicula* was only recorded in BAS. The intensification of agriculture may increase silt input, while reducing the complexity of substrate composition (Walser & Bart 1999; Pease et al 2015).

The genus *Potamanthus* (Potamanthidae: Ephemeroptera) showed high abundance in forested streams (KS and SS). However, the potamanthid nymphs were absent in other sampled streams. This genus shows its potential in differentiating forest streams from other land use streams. Potamanthid mayflies inhabit spaces between substrates, mainly the granules or pebbles (Lee et al 1999). The variety of substrate types in forested streams may provide the suitable habitat to support the high abundance of *Potamanthus*.

This study reinforced the impacts of land uses on aquatic macroinvertebrate diversity. The decline in species diversity, heterogeneity and skewed trophic structures were often indicating an unhealthy ecosystem undergoing stress from anthropogenic activities (Jehamalar et al 2010). In this study, the taxa richness, rarefied richness, diversity, and evenness of the aquatic macroinvertebrates respond to the land use gradient. Aquatic macroinvertebrates remained diverse inside the protected forested streams (KS and SS). Meanwhile, lower diversity at rural and agricultural streams was associated with environmental stress from nearby villages and agricultural activities.

Based on the Shannon-Wiener index, all the studied streams presented high diversity values (median>1.7) (Kra et al 2018). This signified that the sampled streams in Kota Marudu were relatively diverse in aquatic fauna. Shannon–Wiener index had been used as an indication of water pollution, where values higher than 3 represent clean water, between 1–3 represent moderate pollution, and values lower than 1 represent heavy pollution (Mason 2002; Zeybek 2017). The values of diversity recorded in this study were highly compatible with the pollutant parameters. Both forested streams were classified to have clean water, while other land use streams were classified to be moderately polluted. Rarefied richness, after eliminating the bias in the samples, also supported that both protected streams were rich in taxa.

Surprisingly, the aquatic macroinvertebrate metrics were significantly different ($P<0.05$) between the land use types. However, Pielou's evenness index values showed little variation (0.79 to 0.71). This means the aquatic macroinvertebrate taxa is uniformly distributed in the streams. Similar results were documented by Wang et al (2012), where tested macroinvertebrate metrics mostly differed substantially among the forested, agriculture, and urbanized streams.

The EPT and BMWP^{THAI} showed a trend of water quality degradation in a forest-rural-agricultural gradient. Relatively higher BMWP^{THAI} and ASPT^{THAI} scores were found at the forest streams, followed by rural and agricultural streams. Both indices classified the forested streams with "very good" water quality, but the classification was varied for rural streams. Similarly, the ASPT^{THAI} scores were higher in agricultural streams as compared to the rural streams. The contradiction in ASPT^{THAI} water quality classification may be due to the lower sensitivity in discriminating between rural and agricultural streams, as compared to the EPT index and BMWP^{THAI}. In addition, as the biotic indices used were based on the taxa list of other countries, not all taxa collected in this study were included in the calculation. Therefore, loss of information by excluding a particular important taxon may hinder the efficiency of the biotic indices to assess the stream water quality. As such, modifications are recommended by assigning or reassigning suitable tolerance values on the local taxa, for the biotic indices to perform optimally (Barbour et al 1999).

Significant differences of FFGs proportions ($p<0.05$) indicated their usefulness in detecting the stream quality deterioration. Collector-gatherers were abundantly distributed among the sampled streams. The dominant presence of collector-filterers in LS was due to the trichopteran *Cheumatopsyche*. This genus was associated with warmer streams and moderate to high loads of organic matter (Yoga et al 2014). The collectors (gatherers and filterers) dominate the aquatic macroinvertebrate communities in the tropical streams (Astudillo et al 2016; Azmi & Geok 2016; and Shafie et al 2017). The domination of collectors may limit the food availability for other functional groups (Astudillo et al 2016).

Forest streams had more shredders and predators than the human disturbed streams. This confirmed the findings of Fu et al (2016) in Dongjiang River Basin, China, and Shafie et al (2017) in the Liwagu River, Sabah. The perlid perdators (*Etrocorema*, *Phanoperla*, and *Tetropina*) had a higher abundance in forested streams. The increase of predator abundance in the forested streams may be due to the variety of prey taxa for the predators. On the other hand, shredders were found in a small portion (<6%), even though 18 taxa were identified. The lack of shredders was documented in other works in tropical streams (Dobson et al 2002; Mathuriau & Chauvet 2002; Wantzen & Wagner 2006; Mesa 2014; Fu et al 2016). The shredder fauna of Kota Marudu was diverse, but still less than the record in Peninsular Malaysia (22 taxa of shredders) (Yule et al 2009). Shredders like lepidopterans (*Parapoynx)* and plecopterans (*Rhopalopsole*, *Amphinemura*, *Nemoura*, and *Peltoperlopsis*) were more abundant in forested streams. The declining trend of shredder abundance and richness illustrates their rapid decline under the land use practices. Many shredders are notably vulnerable to riparian destruction as they feed on the leaves dropping from the riparian area. Therefore, organic pollution and habitat degradation will lead to the decline of shredders and predators population.

Interestingly, Batutai stream seems to promote larger scraper proportions, such as the algae feeder *Odontanax*. The scraper abundance increases with greater agricultural coverage (Reed et al 1994). The land conversion for agricultural activities near the water bodies reduced the shading of the channel and increased the nutrient runoff. This favors the algae productivity (Belgrano 2005). Therefore, the high nitrate concentration (3.41 mg L^{-1}) recorded in Batutai stream explained the flourish of scraper abundance.

Conclusions. This study strongly emphasized that the anthropogenic land use had significant impacts on biological and ecological characteristics of the aquatic assemblages. Both biodiversity and biotic indices showed significant spatial differentiation between the streams with different land use types. The composition of the functional feeding groups showed significant differences between the forested streams and human-disturbed streams (rural and agricultural streams). Furthermore, shredders and predators can serve as potential indicators of water quality deterioration in tropical streams.

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