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The application of the River Continuum Concept (RCC) on the headwaters of the Sampolawa River in Southeast Sulawesi, Indonesia

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Abstract. *Erif, LOM, Djohan TS, Sudarmadji, Yasin A, Sudia LB, Kahirun. 2023. The application of the River Continuum Concept (RCC) on the headwaters of the Sampolawa River in Southeast Sulawesi, Indonesia. Biodiversitas 24: 290-299.* Benthic aquatic insect communities in temperate regions have been used as bioindicators of a healthy forest in the stream headwaters.This research analyzes the abundance of benthic insects, the quality of water and nutrient sediment, and the response of the insect community in the Sampolawa River. The samples were collected using stratified random sampling methods with a Surber sampler 30 cm x 30 cm, 5 segmented streams, and 200 m with 4 replication. The results show that 19 species of 5 community feeding groups were found, including collector filters, gatherers, predators, scrapers, and shredders. However, the shredders community is very small, at about 2-4 %. The benthic insect aquatic dominance by collector filter with 29 % reflected that input from terrestrial vegetation is Fine Particulate Organic Matter (FPOM). Therefore, it can be deduced that Sampolawa headwaters do not fit with the prediction of the "River Continuum Concept (RCC)"for a typical headwater since the allochthonous energy supply from riparian vegetation is in the form of fine detritus.

Keywords: Abundance of benthic insects aquatic, Baubau city, headwaters of Sampolawa River, river continuum concept

INTRODUCTION

By examining changes in functional feeding groups, species richness, and benthic aquatic insects' tolerance to water pollution, researchers have long utilized benthic aquatic insects to gauge the ecological effects of urbanization. (Gutiérrez-Cánovas et al. 2013; Fierro et al. 2017; Moyo and Richoux 2017), used as bioindicators of river water quality and healthy watersheds (Schmidt-Kloiber and Hering 2015; Wronski et al. 2015; Boyero et al. 2015; Kabore et al. 2016; Tagliaferro et al. 2017; Merritt et al. 2017; Mahler et al. 2017; Balderas et al. 2016; Abbaspour et al. 2017; Keçi et al. 2013; Gawad 2019; Sitati et al. 2021). A healthy watershed is covered by dense riparian vegetation canopy on both edges (Chase et al. 2016; Mariantika and Retnaningdyah 2014; Prasetyo and Hayati 2020). Therefore, the health and integrity of the river ecosystem are necessary to assess the biotic condition of the area through the evaluation of riparian vegetation (Khan et al. 2016). Litters, such as leaves, twigs, grass, and fruit, are the forested headwaters'main source of organic matter. Therefore, the functional group is one of the main factors that determine the health of the forest cover in the watershed upstream (Benfield and Webster 1985; Cummins et al. 1973; Kaushik and Hynes 1968; Nolen and Pearson 1993; Pearson et al. 1989; Petersen and Cummins 1974; Short et al. 1980).

The city of Baubau protected forest is a limestone hills forest, and the Karst landscape that sustains vegetation is one of the ecosystems vulnerable to the disturbance that needs special attention (Achmad 2011). Moreover, the understanding of the vulnerability of the karst environment has reached a new level by providing solutions to the problems of degradation and pollution (Jiang et al. 2014; Zhao 2019; Tang et al. 2019; Gutiérrez et al. 2014; Martinotti et al. 2017; Parise et al. 2015; Van Beynen et al. 2012). Healthy watersheds responded by benthic insects aquatic based on Functional Feeding Groups (FFGs), which can be grouped into the shredder, collector, predator, and grazers (Horne and Goldman 1994). Furthermore, Functional Feeding Groups (FFGs) are a behavior-based classification approach to acquiring food (Ramirez and Gutiérrez-Fonseca 2014). Macroinvertebrates can potentially be used to assess the health of aquatic ecosystems (Bhawsar et al. 2015) and the effect of land use disturbances on river ecosystem functions (De Castro et al. 2016; Mangadze et al. 2019). The approach is considered efficient for describing the condition of aquatic ecosystems through a taxonomic approach (Mishra and Nautiyal 2013; Cummins 2016; Mangadze et al. 2019). Therefore, the composition of functional feeding groups is important for management actions to improve the ecosystem (Ferreira et al. 2012).

The concept of river continuum (RCC) filed by Vannote et al. (1980) related to the health of the watershed stated that river geomorphology changes and responds by biotic communities continuously from upstream to downstream. That predicts longitudinal changes in macroinvertebrate communities taxonomic and functional composition from upstream to downstream (Brasil et al. 2014). RCC describes the entire river system as a continuous series of integrated physical gradients flowing from upstream to downstream. In flow systems, longitudinal connectivity refers to the path along the river's length. The system is seen as a longitudinally interconnected system in which biotic factors are in order, while downstream ecosystem-level processes are closely related to processes upstream (Addo-Bediako 2021). The theory is based on a healthy watershed, where functional shredder groups dominate the benthic communities of aquatic insects. In the area of mid-stream, collector aquatic insects dominate the communities as phytoplankton and zooplankton (Vannote et al. 1980). Adequate characterization of ecosystems requires information on structures and functions (Gessner and Chauvet 2002). Although the structure and composition of communities in ecosystems have been used for a long time, there has been sufficient development of techniques used to complement and describe an ecosystem's ecological integrity. Furthermore, analyses of functional feeding groups are the key components of the river continuum concept by Vannote et al. (1980) and have been applied to assess ecosystem functioning-level in rivers and wetlands (Merritt et al. 1999; Dudgeon 2012; Kumar et al. 2013). In monitoring river quality using biological indicators, the use of measures of FFGs has been adapted in the form of a single feeding group, the ratio between two groups, or using a combination of indices that accommodate several aspects of the trophic level (Pavluk 2000).

The benthic community of aquatic insects is the first food chain in the upstream networks. The existence relies on terrestrial vegetation upstream watersheds. Terrestrial vegetation in the upper reaches of the watershed is also referred to as riparian vegetation, namely the habitat and plant communities along the banks and banks of the river;the vegetation is in the riparian zone, namely the interface between land and streams or rivers, Furthermore, Décamps (2009) states that the riparian zone is a transitional semiterrestrial/semi-aquatic area that is regularly influenced by freshwater, usually extending from the edge of a body of water to the edge of an upland community.

An upstream ecosystem is an open ecosystem based on the input of organic material moving into waters from the litter (Stoker et al. 2017). According to Wallace et al. (2015), degradation of riparian vegetation with urban streams can reduce shredder due to a lack of leaf litter input. The loss of riparian vegetation can also lead to diversity, structural organization, and functional change in river macroinvertebrates (Jinggut et al. 2012). Therefore, shredders rely on allochthonous (leaves that fall or are washed into the water and branches and trees that topple into the stream) and play a role in litter decomposition through riparian vegetation (Brasil et al. 2014). The presence depends on the canopy cover's density, illustrating the importance of riparian vegetation (Mangadze et al. 2019). The vegetation influences the quality and quantity of food for macroinvertebrates (Fierro et al. 2017; Fraaije et al. 2019). Furthermore, it directly affects leaf, soil, and wood allochthonous, considered by benthic composition (Iñiguez–Armijos et al. 2014). It drives the dynamics of food supply for benthic communities of aquatic insects through the microbial decomposition process and impacts the modification of carbon and dissolved organic nutrients (Collins et al. 2016). Vegetation canopy density also affects the quantity of solar radiation that reaches the river and determines primary production to develop macroinvertebrates. However, anthropogenic activity has become the main factor affecting the malfunctioning of the riparian zone (Masese et al. 2014; Larson et al. 2019). As previously discussed in the headwaters, many benthic insect communities are functional shredder groups because of Coarse Particulate Organic Matter (CPOM) (Horne and Goldman 1994; Cummins et al. 1973).

Similar studies have been conducted, such as Birara et al. (2020) examining the distribution and composition of benthic macroinvertebrate functional feeding groups and ecosystem attributes under different land use patterns. The research location focuses on land use around the Kipsinende River, Kenya, which is affected by agricultural activities, grazing, and deforestation. Meanwhile, Makaka et al. (2018) examined the "Longitudinal distribution of the functional feeding groups of aquatic macroinvertebrates and ecosystem integrity of Tokwe River, Zimbabwe."The research focused on the shift from autotrophic to heterotrophic caused by anthropogenic activities. Further research by Doonga et al. (2021) examined spatial variations in the distribution of benthic macroinvertebrate functional feeding groups in tropical rivers."The location focuses on FFGs in non-karst ecosystems in the Philippines. It has been applied to assess the short-term and long-term undetected impacts on the use of physicochemical parameters in river water habitats, including Bacman, Leyte, Bacolod, Dumaguete, and Apo streams. However, the lack of distribution trend of FFGs with the upstream-downstream gradient indicates high variability in environmental conditions. Another research on aquatic insects in karst areas has been conducted in the four seasons country, Croatia (Rađa et al. 2014). From the description above, this report differs from several previous research because it was conducted in a karst ecosystem setting. It is focused on the primary forest upstream of the Sampolawa River, Southeast Sulawesi, Indonesia, that has not been disturbed.

Benthic insect community research was conducted in primary karst forest ecosystems in the upper Sampolawa River, where there were 47 plant species (Erif and Djohan 2015). Furthermore, Powling et al. (2015) detected more than 300 plant species in forests on Buton Island (Powling 2015) as the main source of organic matter and energy source for upstream river organisms because the upstream ecosystem is an open ecosystem whose organic source of energy source comes from terrestrial vegetation litter (Stoker 2017). Meanwhile, this research will determine the abundance of aquatic benthic insects in the upper reaches of the Sampolawa River and will also study the quality of sediments, including NH_4, NO_3, PO_4, and C-Organic. In addition, the water quality conditions include DO, pH, PO_4, temperature, current velocity, and sediment texture.

MATERIALS AND METHODS

Study area

Benthic sampling is located in Upper River Sampolawa, Baubau City, Southeast Sulawesi, Indonesia (Figure 1). Upstream has a bedrock riverbed source rock with a current speed of 4-6 m/s, the river flow ranges from 2-3 m^3/s, and it is clear and undisturbed. The research was conducted in September 2011 and July 2012 during the dry and rainy seasons. The location is a hilly and mountainous forest with a slope between 30-45^o, and the structure of sand-clay soil is rocky and chalky. Temperature and humidity range between 21,3-35,5^{o}C and 76% - 88% (BPS 2012). Climate tabulated results of the Meteorological Station Betoambari Baubau 2012 obtained annual rainfall of 1.832,6 mm. The highest and lowest were in March and August, with an average rainfall of 335.70 mm and 1.20 mm, respectively.

Procedures

Data collection

Benthic aquatic insect samples were collected using a Surber sampler with a 30 × 30 cm^2 collection area and four replicates in each niche, namely rapid, pool and riffle. The point of sampling was determined using a stratified random method to form a straight upstream along 100 m divided into upstream, midstream, and downstream rivers. The Surber sampler was inserted into the river opposite the flow, stirring the sediment slowly. The samples were attached to rocks, wood, or leaves and brushed slowly tobe collected in a Surber sampler. Furthermore, they were introduced into bottles containing 70 % alcohol in each 10 ml solution. The data were tabulated to obtain the density and data genus of aquatic insect larvae. The samples were analyzed at the Laboratory of Ecology and Conservation Faculty of Biology, Gadjah Mada University.

The quality of sediment and water

Sampling sediment quality and water quality using a composite sampler, made by modification of soil cores made of PVC pipe (the pipe) 10 cm long and 7.5 cm diameter embedded 10 cm depth at each sampling point and put in a ziplock plastic. Intake of sediments based on rapid niche and niche pool edge. A sampling at each location, namely the rapid niche of replications 1-10. The number of samples in each niche numbered 1 composite sediment sample. A similar method is used on the niche and the niche pool edge. Sediment samples are taken to the laboratory to analyze the measured water quality in each location: temperature, pH, DO, and current speed. First, the quality of river water chemistry is measured in alkalinity. DO measurements using the Winklers method. Then measure the pH of the river water, river water temperature, and river flow velocity at each sampling point. Data on river sediment quality and the physical quality of water chemistry samples obtained were analyzed at the Laboratory Institute for Agricultural Technology, Yogyakarta.

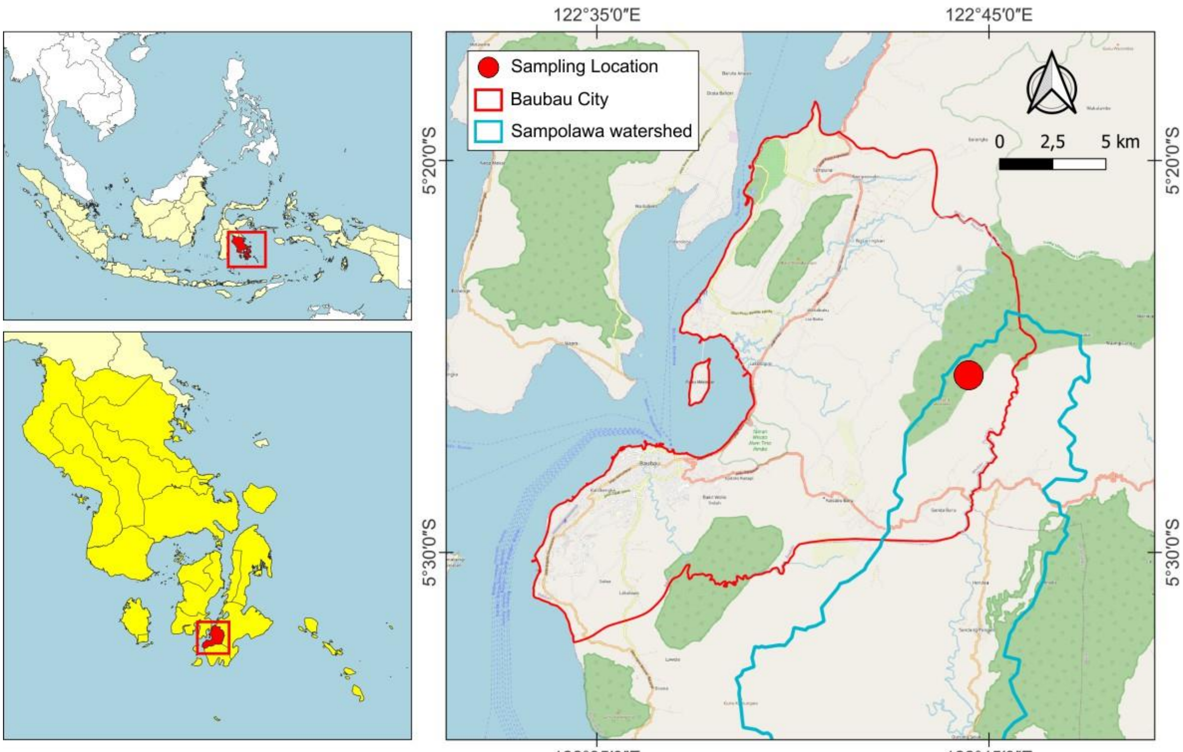

Figure 1. Location of research in protected forest upstream river Sampolawa, Southeast Sulawesi, Indonesia

Data analysis

The benthic community of aquatic insects has been identified in the laboratory at each feeding location. There are several ways to quantify insects, namely: (i) density, (ii) relative density, (iii) frequency, (iv) relative frequency, and (v) Importance Value Index (IVI) is the sum of the values of relative density and relative frequency. Moreover, according to some researchers, IVI value refers to the importance percentage, which provides an estimate or an overall picture of the importance of a species in a community, both animal and plant communities (Brower et al. 1997; Patang et al. 2018). The data were computed, tabulated, and graphed using Microsoft Excel such that patterns could be easily observed.

RESULTS AND DISCUSSIONS

Physicochemical parameters of the river water and substrate quality

The physicochemical characteristics of the upstream of the Sampolawa River vary each season (Figure 2). The temperature in the upstream part is relatively low due to the forest's shade of the water body compared to the middle and downstream (Rezende et al. 2014; Kahirun et al. 2019). In aquatic systems, the quality and quantity of organic matter are important factors that can affect benthic macrofauna communities (Uwadiae 2018). Moreover, it flows through the food web to macroinvertebrates as Dissolved Organic Matter (DOM). In addition, the important role of macroinvertebrates is the recycling and mineralization of organic matter, which comes from waters (autochthonous) and land (allochthonous). Macroinvertebrates also occupy the second and third trophic levels in the water chain.

Demars et al. (2021) stated that the highest C-Organic value was obtained in the rainy season, and soil organic matter levels usually increase with the mean annual rainfall; this is also supported by Muna et al. (2020), who state that rainfall and temperature are climatic factors that can affect the amount of organic matter content. For example, an area that has low rainfall will have warm temperatures. The warmer the temperature of the soil, the faster the decomposition of microorganisms so that the accumulation of soil organic matter will be low. Vice versa, the more the number of organisms, the faster the decomposition process will occur, so the accumulation of organic matter in the soil will also be relatively higher. In addition, high soil moisture levels result in greater biomass production, which provides more residue and potential food for soil biota.

Meanwhile, biological activity requires air and moisture, in line with Jin et al. (2020), which stated that there was an increase in organic matter due to heavy rain. The pH in river water is 6 for rainy and dry seasons. The type of water source and the contaminants determined the pH concentration, which is an important parameter indicating the effectiveness of water management (Kale 2016). The current speed at the research site is 0.4 m/s in the dry season. Meanwhile, the rainy season is 0.6 m/s due to the higher water discharge. According to Wilzbach and Cummins (2018), the benthic insect can adapt to turbulent conditions of river currents, including adaptations in the form of morphological structures such as claws, hooks, suckers, and swipe pads.

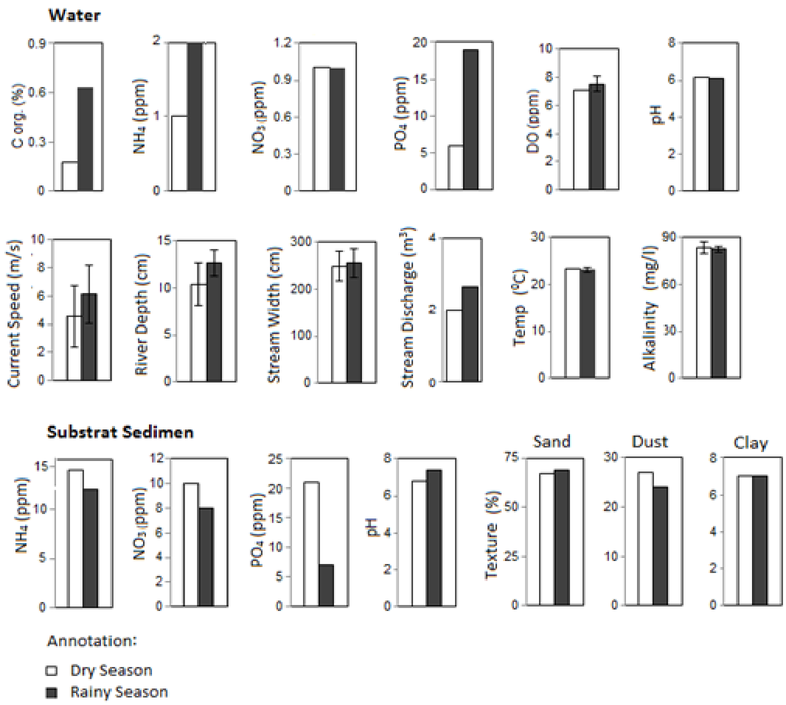

Figure 2. The nutrient content, physical factors, and soil texture in the headwaters of Sampolawa River, Southeast Sulawesi, Indonesia. Chemical parameters for sedimentary substrates include NH_4, NO_3, PO_4, C-organic, and sediment texture and physical parameters for sedimentary substrates. Furthermore, chemical parameters for rivers include DO content, pH, alkalinity, and physical parameters include temperature, current velocity, the width of flow, and discharge

The ammonium content in river water ranges from 1-2 ppm, while in the substrate is between 13-15 ppm. Total nitrogen concentrations can affect the richness of taxons and the percentage of different functional feeding groups of macroinvertebrates. Scrapers, shredders, predators, and collector filters decrease or even disappear while increasing total nitrogen. In contrast, the collector became dominant since nitrogen content was reflected in the NO_3 and NH_4 parameters, ranging from 23-24 mg/l. The enrichment of nutrients and organic matter in water bodies impacts eutrophication. Rathore et al. (2016) stated that the water's nitrogen and phosphorus accumulation causes eutrophication. Another chemical parameter measured with the nutrient content of water is dissolved oxygen. The DO value, measured by concentration, shows the amount of oxygen in the water.

Furthermore, the amount of Sampolawa River water ranged from 6.8 to 7.3 ppm and 7.4 to 7.6 ppm during the rainy and dry seasons, which is optimum for most aquatic organisms (Adu and Oyeniyi 2019). The alkalinity value in river water is between 79-86 mg/l, and it measures the flow of water's ability to absorb hydrogen in pH caused by bicarbonate and carbonate ions (Wilzbach and Cummins 2018). Moreover, based on physical parameters, the texture of the Sampolawa river sediment is dominated by sand. Wilzbach and Cummins (2018) stated that substrate characteristics in shape and surface texture could affect the benthic community structure of aquatic insects. Furthermore, the particle size of minerals from sand to gravel and cobblestone is directly proportional to the increase in diversity, biomass, and abundance of aquatic insect macroinvertebrates but decreases in host and large rocks.

The abundance of functional feeding groups of benthic aquatic insects

This research found five functional feeding groups: shredders, filter collectors, collector gatherers, scrapers, and predators. On upstream of the Sampolawa River, a small feeding group of shredders has been acquired, which accounts for only 2% and 4% of the total volume during the dry and rainy seasons, respectively. Theoretically, the least FFG numbers of shredders reflect the forest fragmentation due to a lack of allochthonous input from riparian vegetation because shredders are detritivores. These organisms eat coarse organic particles in the form of leaves, fruit, and twigs of plants derived from riparian vegetation. However, dense karst forests are not accompanied by abundant feeding group shredders, which could be caused by several terrestrial nutrients entering the stream because of the karst landform. The number of ultramafic rocks is important, resulting in detritus stuck to the stones and not moving into the water. The feeding is caused by a large group of scrapers attached to algae food because of the Sampolawa riparian forest interlock (Figure 3). That increases the productivity of functional group scrapers since aquatic insects are influenced by the physical and chemical properties of the substrate, macrophytes, and landscape factors such as land use or canopy cover and surface geology at various stations (Rezende et al. 2014; Vimos-Lojano et al. 2017; Ding et al. 2017).

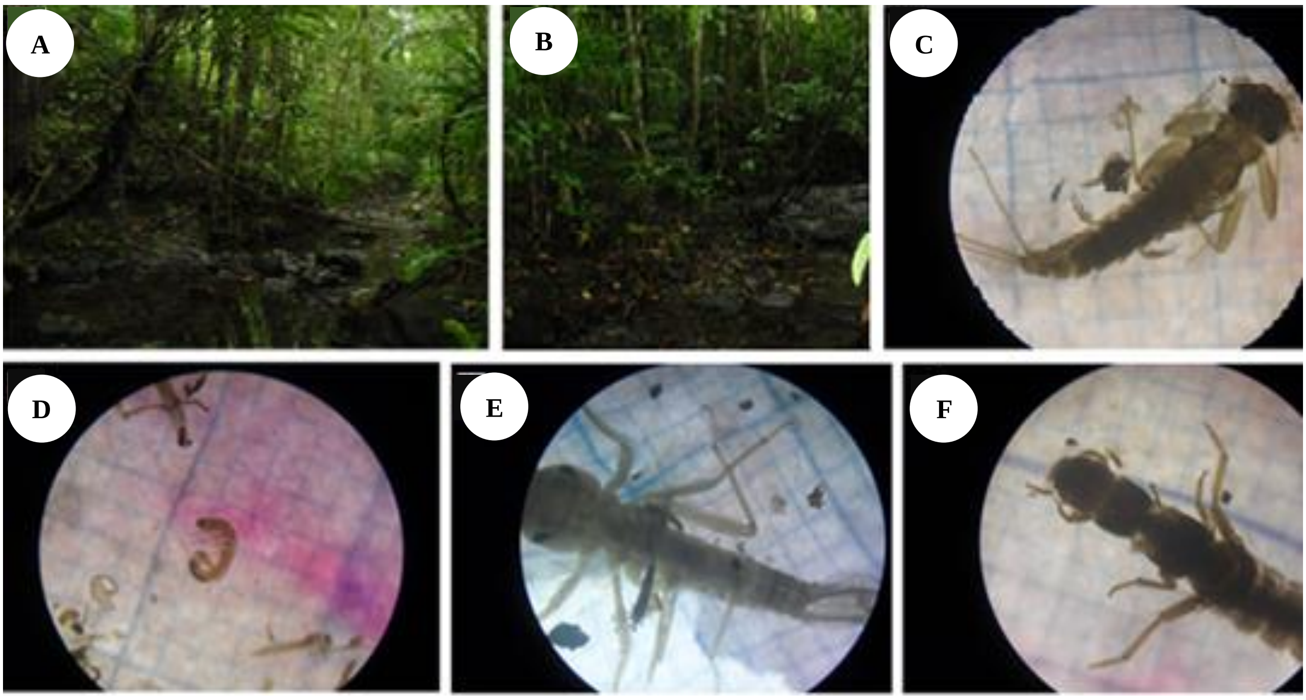

Figure 3. A. Sampolawa River, Southeast Sulawesi, Indonesia with vegetation canopy interlock on both edges, B. Ultramafic rocks in the River of Sampolawa cause detritus to get stuck and not go into the river water body; C. Filtering collector: Ephemeroptera, Ephemerellidae; D. Filtering collectors: Trichoptera, Polycentropodidae. E. Predator: Odonata, Coenagrionidae; F. Predator: Embiidina, Oligotomidae

Therefore, the Sampolawa river riparian forest is in good condition. In the dry and rainy seasons, feeding groups of predators are very abundant at 46% and 44%, respectively (Figure 4). This result was due to the amount of food in the form of a benthic genus of aquatic insects that become prey upstream of Sampolawa. Furthermore, the collector group at the bottom of the river search for dead organisms or other particles fixed in rocks.

According to Nesemann et al. (2017), macrobenthic invertebrates comprise a multi-phyletic assemblage of organisms representing different functional feeding groups and modes. Most macrobenthic invertebrates utilize debris deposited on the bottom of rivers and are fed upon by bottom feeder fish and other invertebrates. Material and nutrient sources are key components of the aquatic food web at higher trophic levels (Wallace and Webster 1996). Moreover, arthropods are a group of aquatic insects whose life cycles are partly in the water and play an important role in the food chain (Leba et al. 2013).

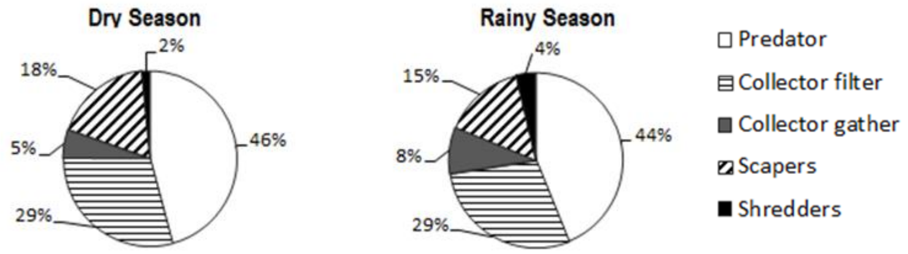

Figure 4. Density relative of benthic aquatic insects in the upstream Sampolawa River, Southeast Sulawesi, Indonesia

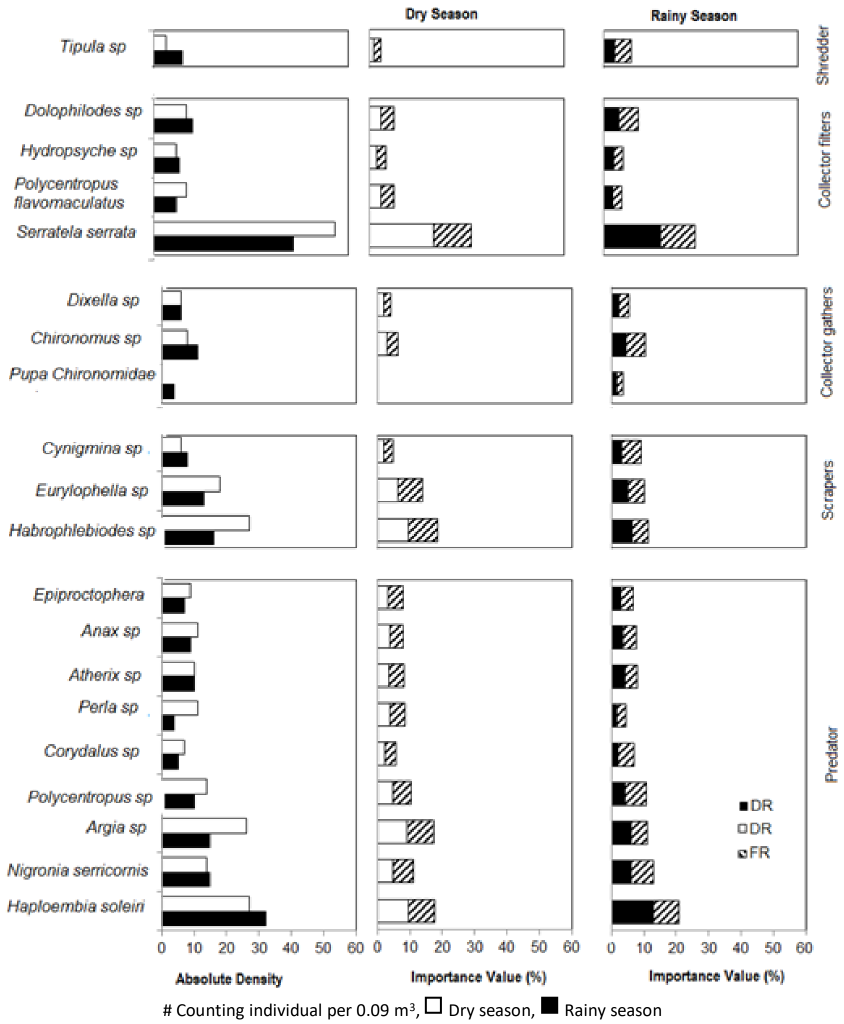

Figure 5. Absolute density and importance value index (IVI) of benthic aquatic insect upstream Sampolawa

The abundance of genus benthic of aquatic insects

A total of 19 species of constituent benthic genera of aquatic insects are found in upstream Sampolawa, namely *Haplombia soleri*, *Serratela serrate*, *Polycentropus flavomaculatus*, *Nigronia serricornis*, *Argia* sp., *Hydrosyche* sp., *Habrophlebiodes* sp., *Dolophilodes* sp., *Corydalus* sp., *Chironomus* sp., *Eurylophella* sp., *Tipula* sp., *Polycentropus* sp., *Perla* sp., *Dixella* sp., *Cynignima* sp., *Atherix* sp., *Anax* sp., and *Epiproctphera*. In general, the density of benthic aquatic insects for both seasons is dominated by *Serratela serrate*, *Haploembia soleri*, *habrophlebiodes* sp., and *Agria* sp., with an absolute density of 56, 27, 27, and 26 in the dry season and 43, 32, 16, and 15 in the rainy season, with counting individuals per 0.09 m^3 (Figure 5).

The benthic abundance of aquatic insects for both seasons tends to be similar and is dominated by *Hamploembia soleiri*, *Argia* sp., and *Nigronia serricornis*, followed by collector filters *Serratela serrate*. According to Wallace and Merritt (1980), the functional group of collector filters has the advantage of the fine detritus input (FPOM), which is *Tipula* sp., and shredder found between 4 and 9 individuals per 0.09 m^3. The low presence of shredders could be related to the leaf type of vegetation, which does not favor these groups but is related to the leaf's palatability. Leaf characteristics can affect shredders' nutritional quality and palatability (Ferreira et al. 2014; Reis et al. 2019). Vimos-Lojano et al. (2020) reported that the presence of shredders as a function of dominant vegetation cover is not significantly related to the amount of organic matter in the riverbed. Moreover, they are replaced by microbial decomposition in tropical and subtropical rivers, which occurs at high rates due to higher water temperatures (Hyslop and Hunte-Brown 2012).

A little feeding group scrapers *Habrophlebiodes* sp., *Eurylophella* sp., collector gathers with constituent genus *Chironomus* sp. and shredders with constituent genus *Tipula* sp. It belongs to the fly family Tipulidae and is a very large genus of insects known as a bioindicator in moderate water quality (Priawandiputra et al. 2018). Moyo and Richoux (2017) stated that the positive relationship between scrapers and total dissolved solids is related to the type of algae assemblage; this was also stated by Jeffries and Mills (1996) that scraper organisms are algae-eating herbivores that grow attached to the substrate. A benthic genus of insects found upstream of Sampolawa is *Cynigmina* sp., from the functional group scrapers *Dixella* sp. and *Hydropsyche* sp. The presence of benthic insects includes the range of low tolerance to physical and chemical factors in the river.

Based on the RCC, the least functional group shredders upstream reflect the occurrence of forest degradation. Even though Sampolawa protected forests have not been disturbed, only a few shredders are found due to the input of the primary forest being FPOM, and the Karst ecosystem has a high porosity (Goldscheide 2019; Abdullah 2021). Therefore, the input into the upstream Sampolawa is FPOM responded by the presence of counting individuals of functional collector filter, in line with the opinion of Djohan et al. (2011) that the dominance of functional group collectors is due to the high content of nutrients in Kali Kuning and Boyong on the southern slopes of Merapi. That indicates that the theory of the river continuum concept does not apply in the headwaters of Sampolawa. Even though the theory of RCC is not applicable upstream, Sampolawa forests are in a healthy state but vulnerable to land cover changes. Therefore, the status as a protected forest should be maintained. Nutrient content in the upstream Sampolawa is high enough in both seasons at 7-21 ppm. Very little light entered the river due to the dense vegetation surrounding it on both sides, which was reflected in the presence of a functional group that scrapers were high enough in seasons at 15-18%.

Analyses of foraging tactics and trophodynamics involve FFGs and provide information on the balance of feeding strategies. In addition, the distributional patterns are related to the physicochemical characteristics of the river-attesting RCC, which are used as bioindicators as part of the Index of Trophic completeness (Pavluk et al. 2000). Various FFGs belonging to macrobenthic invertebrates comprise the gatherers, filterers, predators, scrapers, and shredders (Nesemann et al. 2017).

In conclusion, the dominant presence of the collector indicates that the input of detritus from terrestrial vegetation FPOM forms and contradicts the RCC. Furthermore, the RCC concept does not apply to the River of Sampolawa, a karst forest ecosystem;this happens because the abundance of *Sellaginela flabellate* causes litter decomposition (CPOM) on the forest floor and does not enter river water bodies.

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