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In adaption of river continuum concept as correlation to macroinvertebrates functional feeding group in Cisadane River's headwater

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ABSTRACT

River Continuum Concept (RCC) is an approach that describes the dynamic changes in the river system, the changes that occur are physical conditions (order of the river, canopy cover, and land use) and also the structure and function of communities. Functional feeding groups (FFG) of macroinvertebrates are related to environmental gradients in aquatic systems, including river ecosystem attributes. This study aimed to correlate the function of the macroinvertebrate communities with Cisadane's River headwater conditions based on RCC and also to estimate the attributes of the river ecosystem. This research was conducted in the headwaters of the Cisadane River, West Java-Indonesia. One of Cisadane's River headwaters was located in Mount Halimun-Salak National Park. Macroinvertebrates were collected from four sites inside the park (stations 1, 2, 3, and 4) and from two sites outside the park (stations 5 and 6). Collections were made twice a month, from April to June 2015 using a Surber sampler. The results showed that shredders and predators were relatively higher at stations inside the national park than at those outside the national park. While scrappers and collectors at stations located inside the national park were relatively lower than at stations outside the park. The value of the P/R ratio showed that all of the stations were heterotrophy. CPOM/FPOM ratio represents that shredder availability is high enough at stations inside the national park. While TFPOM/BFPOM ratio is slightly below the normal threshold value. HSI showed that the condition of the riverbed substrate stability is quite good. Composition changes of macroinvertebrates showed suitability with RCC. River ecosystem attributes and abiotic stream characteristics of Cisadane's River headwater support macroinvertebrate life and are in accordance with RCC.

Introduction

The river network can be seen as an integrated system from headwaters to downstream, the physical variables within a stream system present a continuous gradient of conditions and biological parameters will change following the changes in the physical system (Burt, 2013). River Continuum Concept (RCC) is an approach that describes the dynamic changes in the river system, the changes that occur are physical conditions (order of the river, canopy cover, and land use) and also structural and functional of communities (one of them is macroinvertebrate communities). This concept was written by Vannote *et al.,* (1980). This concept is known as a milestone in stream ecology because of its comprehensive evaluation of the structure and function of lotic ecosystems (Doretto *et al.*, 2020).

The macroinvertebrate fauna, which involves numerous taxonomic groups including arthropods (insects, mites, scuds, and crayfish), mollusks (snails, limpets, mussels, and clams), annelids (segmented worms and leeches), nematodes (roundworms), and turbellarians (flatworms) (Mwangi, 2014). There are two general approaches using macroinvertebrates to conduct biological assessments of rivers, i.e. taxonomic and functional approaches. The taxonomic approach is focused on determining some measure of richness or diversity, and the functional approach is to characterize ecosystem conditions. The functional approach is based on easily

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recognized morphological and behavioral characteristics of the invertebrates that are directly to their modes of food acquisition (*functional feeding groups* or FFG) (Ramirez and Gutierrez-Fonseca, 2014). This approach was introduced by Cummins and collaborators in 1973rd.

There are five major functional feeding groups into which stream invertebrates can be classified, i.e. shredders, gathering collectors, filtering collectors, scrapers (grazers), and predators. Different food sources utilized by macroinvertebrates include the epilithic layer that grows on the surfaces of substrates consumed by scrapers; the coarse detritus, composed mainly of leaves falling from riparian vegetation consumed by shredders; the fine detritus, either deposited on the substrate consumed by gatherers or suspended in the water column consumed by filterers; and finally, live animals consumed by predators (Gholizadeh and Heydarzadeh, 2020). This makes FFG particularly sensitive to land use impacts in the watershed, especially streamside (riparian vegetation) that affect the river system flowing through the landscape (Fu *et al.*, 2016). The headwater community structure is largely shaped by riparian vegetation, which adds organic detritus to the channel and shades the river bottom (Vimos-Lojano, 2017). Riparian vegetation is influenced by river size, which makes size categorization very important to the RCC. Based on consideration of stream size, Vannote *et al.* (1980) propose some broad characteristics of lotic communities which can be grouped into headwaters (order 1-3), medium-sized streams (orders 4-6), and large rivers (orders >6). So, this study aimed to correlate the function macroinvertebrate community with Cisadane's River headwater conditions in the adaption of RCC.

Materials and Methods

Location and time of research

This research was conducted in the headwaters of Cisadane River. One of Cisadane's River headwaters was located in Mount Halimun-Salak National Park (06˚42'01.8"S and 106˚41′47.5"E to 06˚39′58.9"S and 106˚37′54.1"E). Macroinvertebrates were collected from four sites inside the park (station 1, 2, 3, and 4) and from two sites outside the park (station 5 and 6). The determination of stations following Strahler stream order classification (McManamay *et al.*, 2019).

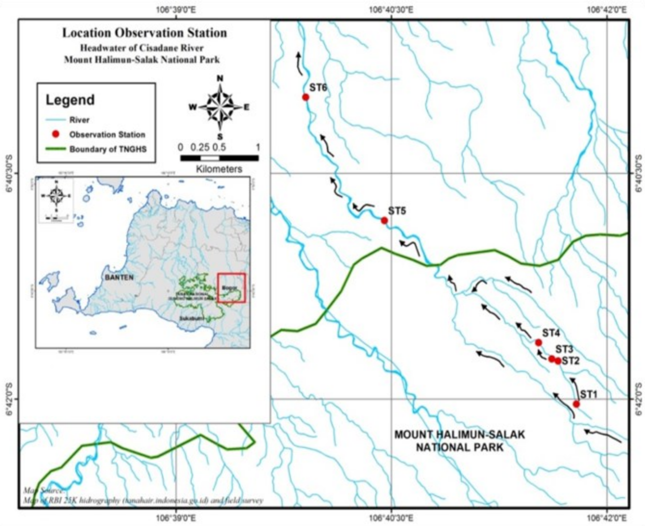

Figure 1. Map of location and observation stations in the headwaters of Cisadane River, West Java - Indonesia.

Station 1 is the smallest flowing stream (first order). Stations 2, 3, and 4 were located downstream of station 1 (second order). Station 5 and 6 were located in the third order of the river (Figure 1). Ten replicates of samples were collected at each station to validate the repeatability of the method. Collections were made twice a month, starting from April to June 2015 using a Surber sampler (frame area 30x30 cm; mesh size 1mm) and preserved using 70% alcohol. Macroinvertebrates were identified up to genus level following identification guides (i.e. McCafferty, 1983; Connecticut Department of Energy & Environmental Protection, 2021) and grouped by using a functional feeding group key from Ramirez & Gutierrez-Fonseca (2014). Some physicochemical characteristics were recorded, i.e. hydrological characteristics, altitude, canopy coverage, land cover, velocity, temperature, and dissolved oxygen (DO).

Data analysis

The abundance composition of the FFG was calculated to characterize the differences in community trophic structure along the gradient of impairment. The FFG ratio was also used as an indicator of river ecosystem attributes (Table 1).

The autotrophy and heterotrophy index (A/H) relate primary productivity to total community respiration. The A/H is an indicator that the stream type is autotrophy or heterotrophy. Autotrophy means the food web source was from autochthonous organic matter-derived algae or rooted vascular aquatic plants. While heterotrophy means the food web source was from allochthonous organic matter resulting from the riparian zone.

The ratio between coarse particulate organic matter and fine particulate organic matter (CPOM/FPOM) provides insights into the quality of the riparian zone cover and the availability of litter used by shredders. The ratio of transport fine particulate organic matter and benthic fine particulate organic matter (TFPOM/BFPOM) measure the availability of relative amounts of coarse and organic particles (transported and stored in the environment). The habitat stability index (HSI) indicates the abundance of bottom substrates for the colonization of macroinvertebrates such as stones, wood, and aquatic plants.

Table 1. FFG ratio as an indicator of river ecosystem attributes.

Ecosystem attributes	Symbols	FFG ratios	Criteria levels
Autotrophy/ Heterotrophy index	A/H	$\frac{Scrapers}{Shredders + Total\ Collector}$	Autotroph > 0.75
Shredder index	CPOM/FPOM	$\frac{Shredders}{Total\ Collectors}$	Shredder availability > 0.25
Filtering-collector index	TFPOM/BFPOM	$\frac{Filtering\ Collectors}{Gathering\ Collectors}$	TFPOM higher than normal > 0.5
Habitat stability index	HSI	$\frac{Scrappers + Filtering\ Collectors}{Shredders + Gathering\ Collectors}$	*Stable substrates* > 0.5

Source: Pereira *et al.* (2020)

Results

A total of 65 taxa were collected during the study, macroinvertebrates composition based on FFG in Cisadane's River headwaters can be seen in Figure 2. Shredders were higher at stations in order of 1 and 2 compared with stations in order of 3. RCC states that shredders are the dominant FFG in low-order streams. In addition, shredders are also abundant at the stations that had vegetation canopy cover higher (inside the national park) than stations that had lack of canopy cover (outside the national park) (Table 2). Meanwhile, scrapers were increased from the area inside the national park to the outside national park.

In this research collectors also increased from the upstream (inside the national park) to the downstream (outside the national park). In other words, the collectors increased from the low order to the higher order. This study also found that predators abundant at stations in low orders, order of 1 and 2 (inside the national park) and then decrease at stations in the higher order (order of 3 that are outside the national park).

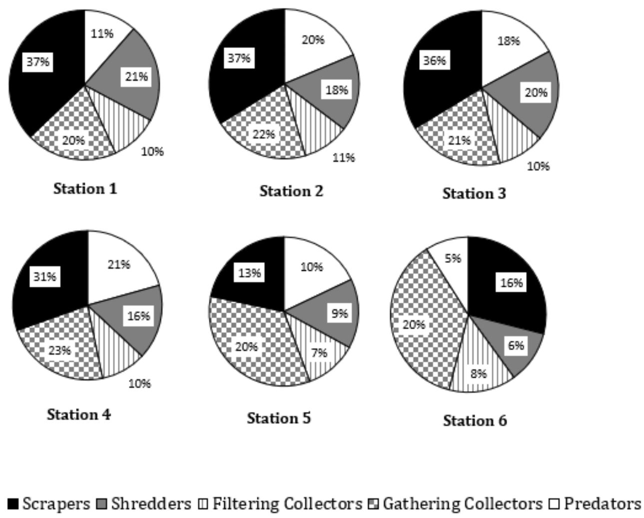

Figure 2. Macroinvertebrates composition based on functional feeding group in Cisadane's River headwater, West Java, Indonesia.

In this study FFG ratio was used as an indicator of river ecosystem attributes (A/H index, CPOM/FPOM, TFPOM/BFPOM, and HSI). The value of the river ecosystem attributes can be seen in Table 2.

Table 2. The value of the river ecosystem attributes.

Ecosystem attributes	Inside national park				Outside national park	
	St 1	St 2	St 3	St 4	St 5	St 6
P/R	0.17	0.38	0.32	0.32	0.34	0.34
cpom/fpom	0.65	0.44	0.52	0.41	0.16	0.13
tfpom/bfpom	0.44	0.49	0.48	0.42	0.40	0.46
HSI	0.44	0.79	0.68	0.68	0.81	0.84

The value of the P/R ratio at all of the stations was under the threshold (<0.75). That means Cisadane's river headwater was heterotrophy. Based on two ratios, the first one was the ratio of CPOM/FPOM and the second was the ratio of transport FPOM to particles retained in the bottom sediment (benthic FPOM).

Stations inside the national park had a cpom/fpom ratio of 0.41-0.65. Those values were higher than the standard level ratio (Shredder availability > 0.25). On the contrary, the cpom/fpom ratio at stations outside the national park was 0.16 and 0.13. Those values were lower than the standard level ratio. While the availability of FPOM transported to FPOM deposited (TFPOM/BFPOM) at all stations was slightly below the normal threshold value. Based on Table 2, HSI at station 1 was below the threshold of 0.5. Meanwhile, at stations 2, 3, 4, 5, and 6 the HSI was above the threshold.

Table 3. Physicochemical characteristics of Cisadane's River headwater.

Parameter	Unit	Inside national park				Outside national park	
		St 1	**St 2**	**St 3**	**St 4**	**St 5**	**St 6**
River width	m	1.7±0.15	3.1±0.1	2.9±0.53	2.5±0.06	11.4±0.26	7.0±0.1
River body width	m	2.7±0.21	4.3±0.15	3.7±0.26	3.0±0.2	14.0±0.26	13.2±0.1
Depth	cm	20.7±0.7	19.4±0.1	20.3±0.5	19.2±0.2	18.1±0.17	18.5±1.32
Altitude	asl	1168	1090	1075	1020	717	584
Canopy coverage	%	90-100	60-80	40-60	0-20	0-10	0-10
Velocity	m/s	0.45±0.05	0.43±0.03	0.37±0.02	0.38±0.03	0.22±0.03	0.28±0.02
Temperature	°C	20.1±0.15	20.3±0.5	20.5±0.5	22.5±0.26	24.1±0.06	27.7±0.4
DO	mg/L	7.08±0.03	6.53±0.15	6.70±0.2	5.67±0.16	5.18±0.05	4.80±0.3

The physical and chemical characteristics of the Cisadane River's headwater can be seen in Table 3. River width and river body width at stations 1, 2, and 3 were smaller than stations 5 and 6 with a value range of 1.7-2.9 m (river width) and 2.7-4.3. m (river body width). While stations 5 and 6, the river width reaches 11.4 m and 7.0 m, and the river body width were 14.0 m and 13.2 m. River width and river body width at Station 4 is slightly different from the other stations, this is because the shape of this river is wide at the beginning and then narrowed. The shape of the river is adjusted by the national park manager for tourism needs.

The average depth at stations inside the national park was slightly deeper than at stations outside the national park, which is in the range of 19.2-20.7 cm. While stations outside the national park were 18.1 cm and 18.5 cm. these stations have a lower depth, due to sand mining and the lack of riparian vegetation. This reduction in riparian vegetation is thought to cause soil erosion into the waters so that sediment enters the waters and causes siltation.

The range of velocity values at stations inside the national park were 0.37-0.45 m/s, while stations outside the national park were 0.22 m/s and 0.28 m/s. The velocity was influenced by the differences in the gradient/slope of the river. The location of the four stations which are within the national park area and also the part of climbing route of Mount Ratu Salak, causes different gradients in the river.

The water temperature was colder at stations 1, 2, 3, and 4 compared to stations 5 and 6, which ranged from 20.08-22.57^{0}C. Meanwhile, stations 5 and 6 are 24.15^{0}C and 27.78^{0}C. Dissolved oxygen (DO) at stations 1, 2, 3, and 4 tend to be higher than stations 5 and 6, with values ranging from 5.07-7.08 mg/L. Meanwhile, stations 5 and 6 were 5.18 mg/L and 4.80 mg/L. DO was higher at stations inside the national park because of the low temperature of the waters, which is causing high oxygen solubility.

Discussion

RCC predicts that in forested regions, the proportion of shredders decreases downstream because of a decline in the availability of coarse particulate organic matter. The concept is suitable with this research that shredders decrease to the down part of the stream with a lack of canopy cover.

Food webs in forest stream ecosystems are typically driven by allochthonous organic input, mainly leaf litter (Neres-Lima *et al*., 2017). Organic coarse particulate matter (leaf litter) input, is generally high in the upper part of the stream, which affects the relative density of shredders. Aguiar *et al.* (2017) reported that streams with high canopy cover are suitable for shredders.

In streams, leaf litter is readily leached, colonized, and decomposed by microorganisms, and consumed by shredders (Newman *et al*., 2015). These processes lead to the production of fine particulate organic matter (FPOM), which is consumed by a suite of collector organisms. The shredders and collectors-gatherers are thus the major primary consumers in forest headwaters streams, providing the main link between the organic inputs and the predators (Graca *et al*., 2015; Rosi-Marshall *et al*., 2016).

Scraper numbers were high at outside the national park than inside the national park area. As Masese *et al.* (2014) research, scraper abundance was higher at open canopy sites. Light availability at open canopy sites affects algae growth and reproduction, and it also affects the scrapers (Canning *et al.,* 2019; Wang *et al*., 2022). Scrapers feed periphyton, non-filamentous algae, especially diatoms, attached to stable surfaces (Cummins, 2018). The highest number of scrapers could be due to an increase in algal production (Addo-Bediako, 2021).

Similar to scrapers, collector numbers were also high outside the national park area. Masese *et al*., (2014) reported that collectors were dominant on less canopy cover. This type of organism was favored by FPOM in open canopy agricultural streams (Masese *et al.*, 2014). St-5 and St-6 are in a location close to agriculture and residence. Gholizadeh & Heydarzadeh (2020) added that as the stations were open and a great part of the river basin drains agricultural land where particulate organic matter tends to be high providing enough FPOM. The abundance of collectors increased because of FPOM increased, and associated with litter decomposition and inputs from tributaries upstream (Canning *et al.*, 2019).

RCC also predicted that the relative abundance of predators had a little decrease along the river from upstream to downstream. Masese *et al.* (2014) reported that predators dominated richness and biomass, respectively, in the closed-canopy streams. Dalu *et al.* (2017) also reported that predator was relatively abundant in the highland stream area. Sites of good riparian quality present higher abundances of some functional feeding groups predators (Mesa, 2014).

Functional group classification is also useful in examining ecologically relevant community-level associations with the physical habitat (Makaka *et al.*, 2018). The ratio between primary production (P) and respiration (R) was used to define ecosystems as heterotrophs (P/R < 1) or autotrophs (P/R > 1) (Wielgat-Rychert & Rychert, 2017). This ratio was the most basic of river ecosystem attributes. Based on the P/R ratio, all of the stations in Cisadane's river headwater were heterotrophy. That means the dominant base of the food chain for invertebrate communities at all river stations is allochthonous detritus, or mostly from the riparian zone. This is also in accordance with the RCC, which groups the upstream part of the river (order 1-3) as having a P/R or A/H value < 1.

River ecosystem attributes also involve particulate organic matter. The CPOM/FPOM ratio is an indicator of the availability of food sources for shredders and a relationship between the riparian zone and also river ecosystem function. Based on CPOM/FPOM ratio, Cisadane's river headwater has high enough shredder availability at stations inside the national park. This is because a lot of allochthonous from riparian vegetation. In contrast at stations outside the national park, shredder availability was low. This is because of the lack of riparian vegetation outside the national park and also canopy coverage of just 0-10% (Table 3). These condition of CPOM/FPOM ratio is in accordance with the RCC which describes the value of the cpom/fpom ratio getting smaller as the order of the river increases.

The TFPOM/BFPOM ratio describes that Cisadane's river headwater has relative amounts of organic particles (transported and deposited) in all observation stations. Those amounts are close to the conditions where suitable to support the life of collectors.

The habitat stability index (HSI) is also a key attribute of the river ecosystem. This stability depends on a variety of basic materials, such as cobbles or boulders, large wood debris, and well-rooted aquatic plants. If the bottom is stable, macroinvertebrates that cling to the surface of large rocks or wood or climb on vegetation to feed on attached algae will be more abundant. The HIS's value at station 1 was low. This is because the velocity at that station is the highest compared to other stations (Table 3) which could an erosion of the riverbed substrate. The higher of the gradient difference, made the velocity also become higher (Effendi *et al.*, 2015). Meanwhile, at the other stations, the value of HSI was high. This indicates that the condition of the riverbed substrate stability is quite good.

The basic concept of RCC states that rivers have physical gradients which are influenced by the surrounding environment, natural disturbance regime, local hydrology, and upstream conditions, and they in turn impact and define the biological components of the stream. It appears that abiotic stream characteristics of Cisadane's River headwater are suitable with RCC.

Canopy coverage and velocity affected the size of organic matter, which is a source of food for macroinvertebrates. High velocity increases the oxygen in the waters through diffusion (Pastore *et al.*, 2019). The low temperature in rivers within the national park area was influenced by the canopy cover of riparian vegetation and the elevation of the river location (Anzani *et al.*, 2016). The understanding of both taxa distribution patterns and the ecological functioning of lotic ecosystems is therefore fundamental for the management of aquatic environments and the reaching of sustainable goals (Gaglio *et al.*, 2021).

Conclusion

Composition changes of macroinvertebrate functional feeding groups in the headwater of Cisadane's River showed suitability with RCC. This is because the environmental conditions like the order of the river, canopy cover, and land use are also consistent with the hypothesis of the concept. According to Vannote's hypothesis, as a river changes from headwaters to the lower reaches, there will be a gradual change in the physical environmental, structural, and functional characteristics of stream communities.

River ecosystem attributes and abiotic stream characteristics of Cisadane's River headwater support macroinvertebrate life and are in accordance with RCC. Overall, results offered evidence that RCC may predict macroinvertebrate benthic community structures in terms of functional feeding groups.

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