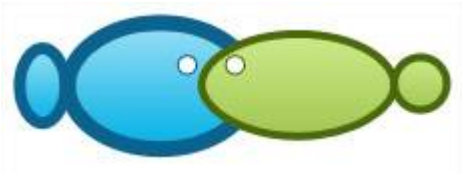

Spatial distribution of macroinvertebrates and stream health status of the Alas-Singkil watershed

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Abstract. Alas-Singkil, situated in northern Sumatra, spans an expansive area of 12,027.18 km^2, making it one of the largest watersheds in the region. This watershed is special because the middle section of the river is home to endemic species, or fish with a highly restricted distribution in the northern Sumatra, and because the middle section of the river is primarily made of sedimentary rock. Therefore, this study aims to determine the distribution of macroinvertebrates and the stream health status of the Alas-Singkil watershed using the SingScore method. Data were collected from June to December 2022 along the Alas-Singkil watershed. The total observation points were 170 locations divided into seven sub-watersheds, while the stream health was evaluated with the Singscore method. The results showed that macroinvertebrates found consisted of 40 families from 14 orders. The families discovered varied in terms of tolerance levels ranging from very tolerant (SingScore 2/Gastropoda, Hirudinea, and Oligochaeta) to very sensitive (SingScore 10/Capniidae and Odontoceridae families). According to the Singscore index, the health of the river within the Alas-Singkil watershed varies across its sections. The downstream segment exhibits a poor health condition, while the middle section is categorized as moderate. Conversely, the upstream portion shows a good health condition, and the tributaries are rated as excellent.
Key Words: bioindicator, macroinvertebrate, river, Singscore, stream, water quality.

Introduction. Watersheds are open-water ecosystems that are significantly influenced by the surrounding environment (Hauer & Lamberti 2017; Dodds & Whiles 2019). The characteristics and changes in water quality conditions within the river basin are the results of land use activities in its environment (Łaszewski et al 2022; Zhang et al 2022; Gani et al 2023). Changes in land use patterns of agriculture, moorland, and settlements, as well as increased industrial activities around the watershed, affect the hydrological conditions of the river (Negash et al 2022; Gule et al 2023). Human activities, including industrial, household, and agricultural practices generate waste that contributes to the decline in river water quality (Camara et al 2019; Muhtadi et al 2020; Crooks et al 2021). In addition, direct river utilization, such as dams for power generation and sandbagging activities also influences changes in habitat and water quality (Bayram & Önsoy 2015; Álvarez et al 2020; Rentier & Cammeraat 2022; Sadhwani et al 2022). These changes inevitably lead to alterations in aquatic biota communities (Lange et al 2018; Rentier & Cammeraat 2022; de Sousa et al 2022).

The water quality index method emphasizes physical-chemical parameters and is used to determine the condition and quality status of river water (Sutadian et al 2016; Uddin et al 2021). However, the use of this method is often inappropriate because rivers are flowing waters where the quality changes rapidly. Experts typically use aquatic animals as biological indicators in determining the condition and quality status of river waters. Aquatic animals such as bacteria, protozoa, macroinvertebrates, and fish can be used as bioindicators (Li et al 2010; Khan & Butt 2023).

Macroinvertebrates are a group of aquatic animals well-suited as biological and ecological indicators of river ecosystems (Blakely et al 2014; Paisley et al 2014; Carter et

al 2017; Orozco-González & Ocasio-Torres 2023). This is due to habitat preference factors and relatively low mobility, making their presence in the waters directly influenced by all materials entering the aquatic environment. Macroinvertebrates are also easier to identify, observe macroscopically, analyze, and preserve compared to other aquatic organisms (Mustow 2002; Blakely et al 2014; Paisley et al 2014). Furthermore, macroinvertebrates function as a bridge between algae and microorganisms (bacteria), as well as act as a source of food for fish and other vertebrates. They also have an intermediate "turnover" rate, with a greater "replacement time" compared to microorganisms (bacteria) with a faster "turnover" rate, and replacement time, while fish have a slow "turnover" rate (Li et al 2010; Carter et al 2017; Dirisu & El Surtasi 2021; Orozco-González & Ocasio-Torres 2023).

Biomonitoring of river water quality using macroinvertebrates has gained widespread popularity in various countries (Eriksen et al 2021). The United States, for example, use the macroinvertebrate sensitivity of Ephemeroptera, Plecoptera, and Trichoptera (EPT) to evaluate the quality of river waters, while Australia employs the term "stream watch" or "bug watch" to evaluate its river waters (Eriksen et al 2021; Chessman et al 2022). Similarly, the United Kingdom utilizes the Biological Monitoring Working Group assessment system commonly known as BMWP/ASPT (National Water Council 1981; Paisley et al 2014). Thailand also developed a BMWP index adapted to the conditions of the country (Mustow 2002). The Public Utilities Board (PUB) in Singapore established a specialized macroinvertebrate biotic index for running water to monitor the long-term health of streams and canals, as well as provide a tool to assess canal ecosystem recovery after restoration projects. This macroinvertebrate-based evaluation of stream habitat is called the SingScore method (Blakely et al 2014). The method is a development of the BMWP of 1978 (Paisley et al 2014) and the BMWPThai (Mustow 2002). Considering that Indonesia shares similar tropical conditions, the SingScore method is a suitable approach for assessing habitat conditions in the Alas-Singkil watershed (Muhtadi et al 2020). This study aims to evaluate the habitat conditions in the Alas-Singkil watershed using the SingScore method.

Material and Method

Description of the study sites. The study was conducted in the Alas-Singkil watershed, which is one of the largest watersheds in Northern Sumatra reaching 12,027.18 km^2. It consists of 7 sub-watersheds with the main river length being approximately 368 km as shown in Figure 1. Administratively, the watershed covers 6 districts in northern Sumatra, 5 districts/cities in Aceh province, and bisects Gunung Leuser National Park in northern Sumatra (Muhtadi et al 2022). The habitat is very unique because in general, the middle of the river is composed mainly of sedimentary rock. The Singkil watershed is also a habitat for endemic species or fish with a highly restricted distribution in the northern Sumatra (Muhtadi et al 2023).

Data were collected from June to December 2022 along the Alas-Singkil watershed and the total observation points were 170 (Table 1), divided into seven sub-watersheds.

Table 1

Observation points of macroinvertebrates in the Alas-Singkil watershed

Sub-watershed	*River segment*						*Total*
	Sub tributary	*Tributary*	*Upstream*	*Middle stream*	*Downstream*	*Swamp*	
Alas	10	14	3	3	-	-	30
Lae Renun	15	10	3	4	-	-	32
Lae Pangkahan	12	7	2	3	-	-	24
Lae Batu-batu	8	5	2	5	-	-	20
Lae kumbih	7	4	2	3	-	-	16
Simonggo	12	11	5	6	1	-	35
Singkil	2	3	-	3	3	2	13
Total	66	54	17	27	4	2	170

The observation points were selected using purposive sampling with several considerations, including: 1) representing each sub-watershed, 2) showing the upstream, middle, and downstream parts of each sub-watershed.

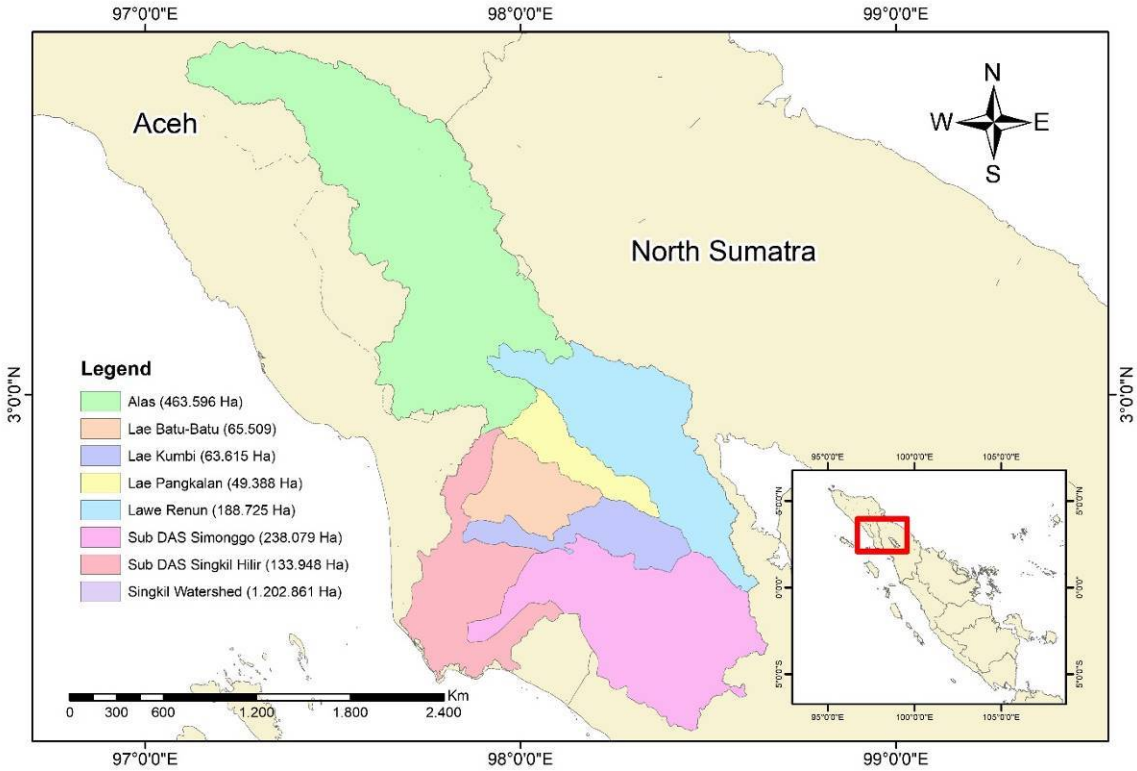

Figure 1. Alas-Singkil watershed (Muhtadi et al 2022).

Macroinvertebrate data collection. Macroinvertebrates were collected using a Surber net (mesh size 1 mm) operated by stirring up the sediment (substrate) of the riverbed. At each point, sampling was carried out in the middle and on both sides of the river. Additionally, macroinvertebrates attached to stones, wood, and plastic found in water bodies were included in the collection. The identification of macroinvertebrates referred to Yule & Sen (2004) and the National Science Foundation, USA (NSF 2023).

Data analysis. The survey was conducted in the Alas-Singkil watershed to assess river quality through its macroinvertebrate biota index. The main tolerance value used was SingScore, but in cases when the family was not found in SingScore, BMWP Thai Score was used (Mustow 2002). All data collected regarding habitat and macroinvertebrates were analyzed qualitatively and quantitatively. The evaluation of river habitat with macroinvertebrates was based on the SingScore method (Blakely et al 2014). The SingScore formula is as follows:

$$\text{SingScore} = \frac{\sum_{i=1}^{s} a_i}{S} \; x\; 20$$

where: S = the total number of taxa in the sample;
ai = the tolerance value for the ith taxon.
The SingScore categories are as follows: likely water quality 0-79 = poor; 80-99 = fair; 100-119 = good; and 120+ = excellent.

Results

Macroinvertebrate richness and composition. Macroinvertebrates found in the Alas-Singkil watershed consisted of 40 families from 14 orders as shown in Table 2. The identified families varied in tolerance levels ranging from very tolerant (SingScore 2/ Gastropoda, Hirudinea, and Oligochaeta) to very sensitive (SingScore 10/Capniidae and Odontoceridae families). The macroinvertebrates were composed mainly of insect groups

(73%), while the rest included Decapoda (18%), gastropods (2%), and others (7%). According to previous studies, insect larvae and nymphs were identified as the main macroinvertebrates benthic constituents in upstream as well as mid-river waters dominated by rocky and gravel substrates (Wibowo et al 2017; Muhtadi et al 2020).

Palaemonidae and Gerridae were the most distributed and abundant families in the Alas-Singkil watershed, consisting of 823 and 626 individuals, respectively. Both were found in almost every location in upstream, midstream, and downstream waters, as well as in the swamp. These families are macroinvertebrate groups with a wide distribution and can live in a variety of freshwater habitats, displaying considerable tolerance to various water conditions (Yule & Sen 2004). The *Atyopsis* shrimp group (Palaemonidae) can even live between rocks in swift waters (Desrita et al 2020; Muhtadi et al 2023). Similarly, certain Gerridae species are capable of surviving in rough waters (Yule & Sen 2004). The order Hemiptera was found as the most abundant and widely distributed in the Alas-Singkil watershed with a population of 1218 individuals accounting for 25% of the macroinvertebrates (Figure 2). This macroinvertebrate can live in a variety of habitats and environmental conditions of diverse river waters, both good (natural) and bad (Yule & Sen 2004).

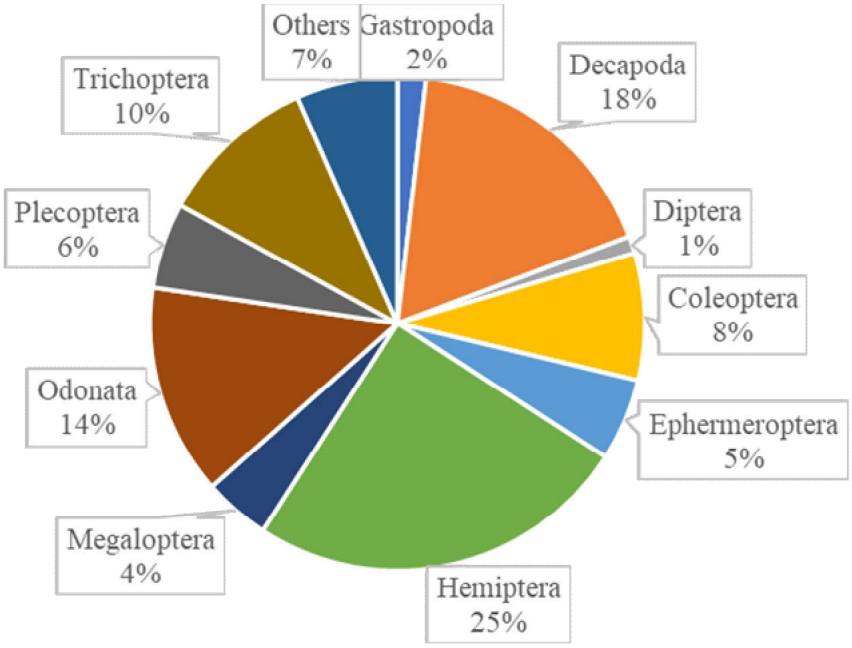

Figure 2. Composition of macroinvertebrates found in the Alas-Singkil watershed.

Diptera and Gastropoda groups were sparsely represented and had a narrow distribution, with 54 (1%) and 90 individuals (2%), respectively. In general, Diptera and Gastropoda were found in poor water conditions, specifically in the downstream part of the river where the conditions tend to experience many changes and ecological pressures. This was consistent with previous studies which found both families in polluted water quality conditions (Yule & Sen 2004; Al-Shami et al 2010; Harahap et al 2021). Families with higher sensitivity can only thrive in favorable environmental conditions and are consequently used as a marker of water quality. Conversely, families with higher tolerance can withstand extremely poor environmental conditions and are used as a marker of poor water quality (Blakely et al 2014; Paisley et al 2014; Muhtadi et al 2020; Harahap et al 2021).

Macroinvertebrate diversity in the Alas-Singkil watershed was highest in locations with good conditions, specifically in creeks and sub-creeks. In contrast, the lowest diversity was found in the downstream part, regarded as a "polluted" location due to agricultural/plantation activities. It can also be inferred that macroinvertebrates are more predominant on gravel and rocky substrates than sandy. This preference was exemplified by the attachment of the highly sensitive nympha larvae to rocky substrates, while the substrate in the downstream part was mud and silty sand (Muhtadi et al 2023).

Table 2

Macroinvertebrate groups and their distribution in the Alas-Singkil watershed

No.	Order/Family	Tolerance SingScore/ BMWP Thai Score	Sub-watershed							Total
			Alas	Lae Renun	Singkil	Simonggo	Lae Batu	Lae Kumbih	Lae Pangkalan	
1	Architaenioglossa/Ampullariidae	3	33	27	62	45	21	10	23	221
2	Gastropoda/Thiaridae	2	-	-	49	-	-	-	-	49
3	Gastropoda/Planorbidae	2	-	-	27	-	-	-	-	27
4	Gastropoda/Pachychilidae	2	-	-	14	-	-	-	-	14
5	Coleoptera/Elmidae	5	6	-	-	-	-	-	-	6
6	Coleoptera/Epilampridae	5	-	5	-	4	-	-	-	9
7	Coleoptera/Dytiscidae	5	-	4	-	3	-	-	-	7
8	Coleoptera/Gyrinidae	5	16	19	-	13	12	3	15	78
9	Coleoptera/Hydrophilidae	6	75	29	-	31	27	0	24	186
10	Coleoptera/Psephenidae	5	27	24	5	22	14	11	15	118
11	Decapoda/Palaemonidae	7	176	109	52	175	103	102	106	823
12	Decapoda/Parathelphusidae	9	5	-	2	5	4	4	4	24
13	Diptera/Empididae	4	4	-	-	-	-	-	-	4
14	Diptera/Simuliidae	7	8	-	-	10	5	8	5	36
15	Diptera/Ceratopogonidae	3	3	-	-	-	-	-	-	3
16	Diptera/Ptychopteridae	4	5	-	-	-	-	-	-	5
17	Ephermeroptera/Baetidae	7	4	4	-	6	6	3	2	25
18	Ephermeroptera/Heptageniidae	9	44	50	9	47	25	25	36	236
19	Hemiptera/Gerridae	5	140	148	24	151	51	37	75	626
20	Hemiptera/Nepidae	5	9	35	6	37	36	13	21	157
21	Hemiptera/Notonectidae	8	13	16	0	12	11	9	9	70
22	Hemiptera/Naucoridae	7	5	7	0	6	6	2	8	34
23	Hemiptera/Veliidae	7	70	73	12	69	30	24	53	331
24	Rhynchobdellida/Glossiphoniidae	2	2	4	5	3	0	0	4	18
25	Isopoda/Asellidae	3	-	0	33	0	0	0	0	33
26	Megaloptera/Sialidae	8	29	30	4	27	23	21	21	155
27	Megaloptera/Corydalidae	4	8	6	2	11	8	8	13	56
28	Odonata/Aeshnidae	3	-	-	-	5	-	-	-	5
29	Odonata/Calopterygidae	8	4	5	0	9	4	4	4	30
30	Odonata/Coenagrionidae	3	43	38	13	50	27	20	26	217
31	Odonata/Cordulegastridae	6	-	-	-	3	-	-	-	3
32	Odonata/Corduliidae	5	12	-	-	9	11	12	9	53
33	Odonata/Gomphidae	8	15	12	0	15	10	9	5	66
34	Odonata/Lestidae	6	3	6	2	5	4	7	8	35
35	Odonata/Libellulidae	4	43	57	12	56	29	24	41	262
36	Tubificida/Tubificidae	2	8	8	17	7	0	4	6	50
37	Plecoptera/Capniidae	10	14	12	0	18	14	8	7	73
38	Plecoptera/Perlidae	9	39	37	6	41	31	16	29	199
39	Trichoptera/Odontoceridae	10	16	12	-	26	13	9	17	93
40	Trichoptera/Hydropsychidae	7	77	79	14	74	57	52	61	414
	Total		956	856	370	995	582	445	647	4851

Macroinvertebrate richness in the Alas-Singkil watershed was more diverse than in other watersheds in Indonesia. The diversity in the Batangtoru watershed (North Sumatra) only consisted of 11 orders and 17 families (Muhtadi et al 2020), while in the Bilah River, only 27 taxa were found (Harahap et al 2021). In several rivers within Kalimantan, only 21 taxa were found (Patang et al 2018), while 7 taxa were identified in the Purwokerto River (Wibowo et al 2017). Additionally, various rivers in Malang consisted of 27 taxa (Kartikasari et al 2013). Macroinvertebrates in the Winongo and Gajah Wong rivers (Yogyakarta) were composed of 21 and 26 families, respectively (Nugrahaningrum et al 2017).

Stream health. Based on the results of the SingScore calculation, the conditions in the Alas-Singkil watershed ranged from poor to excellent (Table 3 and Figure 3). Poor water conditions were found in the lower section (Singkil subwatershed), excellent conditions were observed in the upper section of the main river and its tributaries (Table 3), while the middle stream was generally in fair to good condition. In general, the condition of the water quality in the watershed was considered to be in a good category, except in the downstream and Singkil swamp. This was consistent with the results obtained by Muhtadi et al (2023) wherein water quality assessed using in-situ measurements, showed good parameter values for the life of aquatic organisms. The pH and oxygen values as limiting factors of water quality parameters were adequate for the growth of aquatic organisms. The limiting factors in terms of environmental parameters in the Wampu watershed were substrate characteristics and currents. Flow was found as the main limiting factor for the life and abundance of aquatic organisms in the river.

The condition of the Alas-Singkil watershed was not significantly different compared to the Batangtoru watershed and the Malang River which ranged from poor to excellent (Kartikasari et al 2013; Muhtadi et al 2020). Poor water conditions in the Batangtoru watershed were also found in the downstream part of the river (Muhtadi et al 2020). Based on the status of several other watersheds (rivers) in Indonesia, the Alas-Singkil watershed was considered to have better water quality. Karang Mumus River (East Kalimantan) in 2018 was found to be in poor condition (Patang et al 2018), while the Winongo and Gajah Wong Rivers (Yogyakarta) were reported to be in poor-to-good condition (Nugrahaningrum et al 2017).

Table 3

Singscore calculation results by river segment in the Alas-Singkil watershed

Sub-watershed	*River segment*						*Category*
	Sub tributary	*Tributary*	*Upstream*	*Middle stream*	*Downstream*	*Swamp*	
Alas	121.27	117.19	140.48	109.37	-	-	Good-excellent
Lae Renun	122.31	114.68	100.00	104.43	-	-	Good-excellent
Lae Pangkahan	122.24	116.90	117.84	90.89	-	-	Fair-excellent
Lae Batu-batu	141.33	112.85	136.25	94.19	-	-	Fair-excellent
Lae kumbih	134.29	122.50	153.47	92.53			Fair-excellent
Simonggo	127.91	108.99	138.09	97.64	90.00	-	Fair-excellent
Singkil	92.22	71.56	-	93.26	56.35	63.75	Poor-fair

Description: likely water quality 0-79 = poor; 80-99 = fair; 100-119 = good; 120+ = excellent.

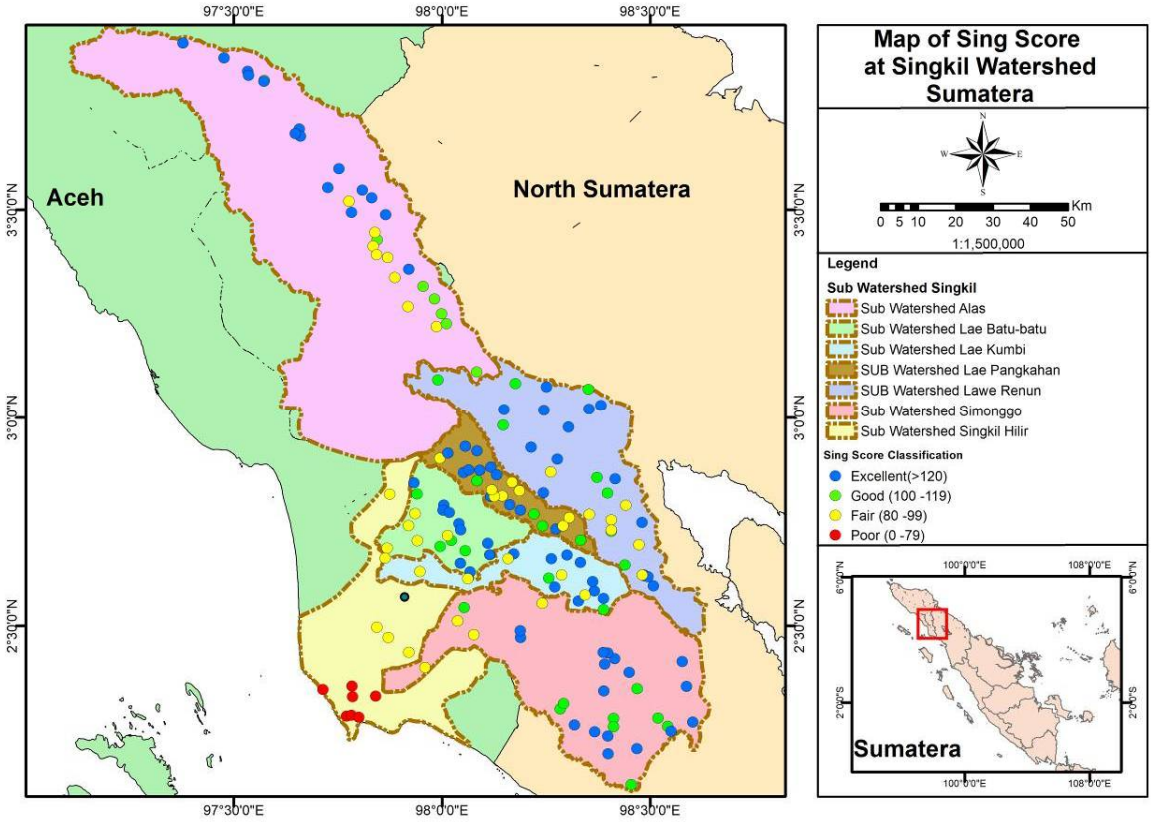

Figure 3. Stream health status of Alas-Singkil watershed, based on SingScore.

Conclusions. The macroinvertebrates found in the Alas-Singkil watershed consisted of 40 families from 14 orders. The identified families varied in terms of tolerance levels, ranging from very tolerant (SingScore 2/ Gastropoda, Hirudinea, and Oligochaeta) to very sensitive (SingScore 10/Capniidae and Odontoceridae families). Based on the SingScore index, stream health conditions in the Alas-Singkil watershed were poor downstream, fairly good in the midstream, and good-excellent in the upstream and its tributaries.

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Conflict of interests. The authors declare that there is no conflict of interest.

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