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Habitat characteristics and biodiversity of nekton in the Alas-Singkil River Basin, Northern Sumatra, Indonesia

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Abstract. *Muhtadi A, Leidonald R, Fauzia AD. 2023. Habitat characteristics and biodiversity of nekton in the Alas-Singkil River Basin, Northern Sumatra, Indonesia. Biodiversitas 24: 3673-3689.* The Alas-Singkil watershed ecosystem is an essential habitat for the diversity of flora and fauna in the North Sumatra region. This study aims to describe the habitat characteristics and distribution of ichthyofauna in the Alas-Singkil watershed. Observations and data collection were carried out in 2021-2022 in all river segments in the Alas-Singkil watershed, including the downstream, swamp, oxbow lake, middle, upstream, and tributaries. Habitat characteristics in the Alas-Singkil watershed are very diverse. Some swamps in the main river's lower to middle reaches allow the ichthyofauna to migrate laterally. In the middle of the main tributaries (sub-watersheds) to the upstream (most) have habitat characteristics dominated by sedimentary rock substrates with relatively moderate-strong currents. The upper reaches of the main river are dominated by rocky substrates with clear, low-medium flowing waters. During observations in the Alas-Singkil watershed, 99 species of fish from 39 families, 9 species of shrimp, 1 species of freshwater crab, 1 species of freshwater turtle, and 1 species of crocodile were collected. Spotted barb (*Barbodes binotatus*), Blue panchax (*Aplocheilus panchax*), and Mahseer fish are fishes often found and widely distributed in the Alas-Singkil watershed. The nekton found in the Alas-Singkil watershed is included in the Least Concern (LC) category at 71% and Data Deficient (DD) at 14%. However, there are 2 species (2%) in the Endangered (EN) category and 6 species (5%) in the Vulnerable (VU) category; *Ompok breviristus* and *Clarias microspilus* are species categorized as Endangered Species.

Keywords: Basin, biodiversity, habitat, rare species, restricted area, Sumatra

INTRODUCTION

A watershed is a land area that is a unity of rivers and tributaries, which functions to accommodate, store, and drain water from rainfall to the ocean. Watershed ecosystems are very important in maintaining the existence of water on the earth's surface through the hydrological cycle (Hauer and Lamberti 2017; Dodds et al. 2020). Ecologically, watersheds play an important role in maintaining biodiversity as a habitat for various aquatic organisms (Muhtadi et al. 2017, 2020; Desrita et al. 2018, 2020). Socio-economically and culturally, watersheds play an important role in supporting community activities through transport, agriculture, and tourism (Rauf et al. 2015). Watersheds are also a source of energy through hydropower plants as well as renewable energy alternatives through the development of micro hydro/mini hydropower energy (Taufiqurrahman and Windarta 2020; Rahayu and Windarta 2022).

Indonesia has very abundant watersheds, of which there are at least 5,590 main rivers and 65,017 tributaries, with the total length of the main river reaching 94,573 km. Indonesia's total area of watersheds reaches 1,512,466 km^2, with the number of watersheds reaching 16,958 (MPWHS 2015). Alas-Singkil watershed is one of the largest in Northern Sumatra, reaching 12,027.18 km^2. Alas-Singkil watershed consists of 7 sub-watersheds, with the length of the main river reaching 368 km (Muhtadi et al. 2022). The Alas-Singkil watershed divides the Leuser Mount National Park and is administratively included in the Province of Aceh and North Sumatra regions. The Alas-Singkil watershed covers 6 districts in North Sumatra province and 5 districts/cities in Aceh province.

The Alas-Singkil watershed ecosystem is an important habitat for northern Sumatra's diverse flora and fauna. The length of the main rivers and tributaries that stretch from the Toba and Leuser plateau areas to the Indian Ocean in the southwestern part of Sumatra Island are suitable habitats for aquatic organisms (Muhtadi et al. 2022). This follows Desrita et al. (2020) and Odum and Barrett (2005), which state that rivers and their tributaries are suitable habitats for aquatic organisms. Based on reports from various studies conducted by experts in the Singkil watershed, many found and concluded that the Singkil watershed is a habitat for endemic/limited fish in the North Sumatra Region (Lumbantobing 2014; Muhtadi et al. 2022). Thus, the Singkil watershed is a haven for certain fishes whose distribution is limited to northern Sumatra.

Historically, the Alas-Singkil watershed has long been utilized by the community for various activities, such as agriculture, fisheries, and transportation (Gadeng et al. 2020; Muhtadi et al. 2022). The Alas-Singkil watershed has been built as a Hydropower / Micro Hydro Power Plant. There are at least 28 locations that have the potential to be developed as hydropower/micro-hydro, and 4 hydropower plants are already in operation (MEMR 2021). Various activities and land use in the Alas-Singkil watershed will impact habitat destruction and decrease river water quality. Previous research in the Alas Singkil watershed was still limited to one location, not yet covering a single watershed. For example, studies by Hadiaty (2005) on the Ketambe River (Alas sub-watershed), Simanjuntak (2012) on the tributaries of Sopokomil (Pangkalan sub-watershed), and Maghfiriadi et al. (2019) at the Soraya Research Station, Alas River (Alas Sub Basin). For this reason, it is necessary to study habitat characteristics, monitoring, and data collection on the distribution of ichthyofauna in the Alas-Singkil watershed. Therefore, this study was conducted to map the habitat characteristics and distribution of ichthyofauna in the Alas-Singkil watershed.

MATERIALS AND METHODS

Study area

Sampling was conducted from 2021 to 2022 in the Alas-Singkil watershed (Figure 1). Ichthyofauna samples were captured/taken from various locations in the Alas-Singkil watershed. Some of these locations include the river's lower, middle, and upper reaches, both the main river and its tributaries, and several other locations, such as oxbow lakes and swamps (Table 1).

Procedures

Habitat characteristics and water quality

The habitat characteristics observed in the Alas-Singkil watershed consist of physical characteristics and water quality. The physical characteristics observed were mesohabitat type and bottom substrate, river width, river body width, depth, current, discharge, land slope, and surrounding land conditions. The observed water quality was brightness, turbidity, temperature, pH, and dissolved oxygen. Tools and methods for measuring habitat characteristics can be seen in Table 2.

Nekton sampling

In shallow river waters, especially in the upper reaches and tributaries, nekton is caught with backpack electrofishing units with 12 volts and 9 amperes of electric current. Electrofishing is operated by traveling along both banks of the creek. The electrofishing operator moves opposite to the river current (moving upstream), picks up unconscious fish, and puts them in a plastic bag. In addition, nektons are also caught with traps and nets. In the middle and lower reaches and swamps, nekton was caught using traps.

Samples were then photographed and preserved in 10% formalin solution, labeled with the local name of the fish, location/station, collection date, collector's name, and other necessary information. Identification was done at the Aquatic Environment Laboratory, Faculty of Agriculture, Universitas Sumatera Utara. Fish identification refers to various literature (Kottelat et al. 1993; Kottelat 2013). Macroinvertebrate identification refers to Wowor et al. (2004).

Data analysis

Frequency of occurrence is determined by the number of stations where fish are found divided by the number of observation points (215 observation points). Frequency of occurrence is determined to determine the level of spread of nekton in the Alas-Singkil watershed.

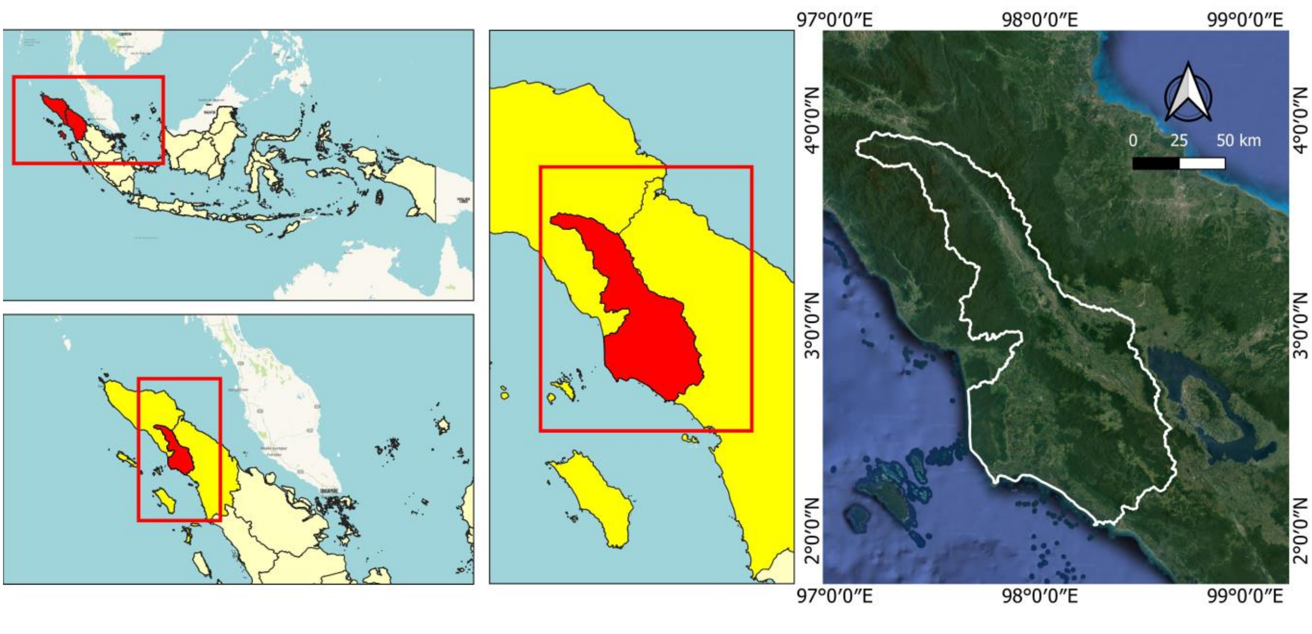

Figure 1. Alas-Singkil watershed, Northern Sumatra, Indonesia

Table 1. Ichthyofauna data collection locations in the Alas-Singkil watershed, Northern Sumatra, Indonesia

Sub watershed	Order								Non-order
	1	2	3	4	5	6	7	8	
Alas	4	10	10	8	4	1	1		
Lae Renun	2	6	12	10	3	6	1		
Lae Pangkahan	3	5	7	4	2				
Lae Batu-batu	2	6	5	3	2				
Lae kumbih	2	6	8	4	2				
Simonggo	4	10	15	12	4	2	1		
Middle stream								3	
Downstream		2	2					3	
Oxbow lake									3
Swamp									6
Singkil Swamp Forest									3
Oil palm plantation channel									6

Table 2. Physicochemical data collection and mesohabitat classification

Parameter	Method	Instruments/ measurement
Mesohabitat	Visual method	Visualization
Land use	Visual method	Visualization
River slope	Visual method	Visualization
Substrate	Visual method	Visualization
Depth (m)	Manual	Scale wand
Wetted river (m)	Map delineation	Arc Gis
River width (m)	Map delineation	Arc Gis
Flow (m/s)	Propeller	Current meter
Water transparency (m)	Refraction	Secci disc
Temperature (°C)	Sensor	Milwaukee DO meter
TDS (mg/L)	Sensor	TDS/ EC meter HM Digital
Conductivity (µs/cm)	Sensor	TDS/ EC meter HM Digital
Turbidity (NTU)	Sensor	Lutron Turbidity meter 2016
DO (mg/L)	Sensor	Lutron DO meter 5510
pH	Sensor	Atago DPH-2 Digital

The diversity of the nekton community in the Alas-Singkil watershed can be determined by the Shannon-Wiener diversity index (H'), evenness (E), and dominance (D) (Odum and Barrett 2005; Krebs 2014). Nekton diversity was calculated using the diversity index of Shannon and Wiener (1963) in Odum and Barret (2005) with the formula:

$$H' = -\left(\sum pi \ln pi \right)$$

Where:
H' : Species diversity index,
ni : number of individuals of each species,
N : Total number of individuals
Pi : Probability of importance for each species = ni/N,

The evenness of individuals caught between species (equitability) was calculated using the equation:

$$E = H'/H`\max$$

Where:
E : Shannon-Wienner evennes index,
H : Balance of species,
H` max: Maximum diversity index (lnS),
S : Total number of species

The dominance index was calculated according to Simpson's index (Odum and Barrett 2005).

$$C = \sum \left(\frac{ni}{N}\right)^2$$

Where:
C : Dominance index,
ni : number of individuals of each species,
N : Total community individuals

RESULTS AND DISCUSSION

Habitat characteristics and river water quality

In general, the condition of the primary forest in the Alas-Singkil watershed is found in the western part (Alas sub-watershed), part of the Leuser Mount National Park. Other sub-watershed areas are palm oil plantations (downstream-middle), other plantations, and settlements (upstream). This variety of land use will provide opportunities for declining river water quality due to potential inputs from human activities along the watershed. River slope conditions in the Alas-Singkil watershed are generally steep, except in the Alas sub-watershed. Steep conditions are mainly found in the middle stream, at the tributaries and main tributaries. Most substrate types are sedimentary rocks in the Simonggo, Renun, Pangkahan, and Kumbi sub-watersheds (see Figures 2-5). The sub-watershed tributaries have only a small portion of rock, gravel, and sand. Sedimentary rock conditions are found in the sub-watershed, so it is suspected that eels cannot go upstream of the sub-watershed Simonggo, Renun, Pangkahan, and Kumbi. Eelfish is only found upstream of the alas river, where the substrate is rocky and gravel.

The characteristics of the rocky substrate (loose rock) and fast flow are the characteristics of the upstream segment of the river, but in the Alas-Singkil watershed, it is found in the middle to upper segments with sedimentary rocks. This type of river is very rare in Indonesia; generally, the upper reaches of the river are of the loose rock type (Muhtadi et al. 2017) or gravel/sand (Muhtadi et al. 2020). Steep and sharp slopes, large rock substrates, fast flow, and narrow river widths characterize rivers in the upland segment. Downstream segments are characterized by gentle slopes and sand or mud substrates (Muhtadi et al. 2017, 2020; Negro et al. 2021).

The color of water in the Alas-Singkil watershed is generally turbid, brownish, and yellowish, except in the Alas sub-watershed and its tributaries. Turbidity values in the downstream and middle sections are 21.31 -73 NTU, and the upstream section is not more than 10 NTU (Table 3). The high turbidity in the middle and downstream is caused by particles carried upstream and runoff due to rain in the upstream, especially in the upstream with high land clearings openings such as in Dairi, Humbang Hasundutan, and Fak Fak Barat Districts (upstream sub-watershed Simonggo river, Lae Renun, and Lae Kumbih).

The condition of the bottom water substrate can affect the color of the water and the turbidity of the water. The waters tend to be turbid, with higher turbidity values at observation points with sandy or muddy substrates. This is similar to what Muhtadi et al. (2020) obtained on the Batangtoru River, that rocky river segments tend to be cleaner than sandy substrates.

The temperature range in the waters of the Alas-Singkil watershed ranged from 20.3-21.1^{o}C in the upper reaches, 22.1-25.1^{o}C in the middle reaches, and 26.6-27.0^{o}C in the lower reaches. Temperatures in the Simongoo tributaries ranged from 24.1-26.9^{o}C. Higher temperatures were found in the downstream and tributary locations, associated with lower elevations and more open land cover. The low temperature in the upstream section is due to the elevation from sea level. Temperature is influenced by season, time of measurement, and altitude/latitude (Muhtadi et al. 2017, 2020). In addition, the pH value in the upstream waters of the Alas-Singkil watershed ranged from 6.5-8.0, except in the swamp, which reached 3.8-4.4. The pH value of water in the upper part tends to be alkaline because of the low organic matter, so the level of organic decomposition is low. Thus, oxygen is always higher, and CO_2 is low, causing the pH tends to be alkaline. The pH value in the swamp tends to be very low due to the high decomposition of organic matter (Rohim et al. 2022).

Dissolved oxygen concentrations in the Alas-Singkil watershed ranged from 8.5-8.7 mg/L in the upper, 8.3-8.9 mg/L in the middle, and 5.4-6.3 mg/L in the lower reaches. While in the tributary section, DO values ranged from 7.4-8.4 mg/L. The high dissolved oxygen concentrations in the upper and middle reaches, including the tributaries, are due to the strong currents in these areas. Flowing waters tend to have a higher dissolved oxygen content than stagnant waters, as water movement allows oxygen diffusion from air to water (Hauer and Lamberti 2017). This can be seen in Table 1, where the high current sampling location shows high DO values in each data collection segment. However, DO in the swamp section is also very low, as obtained by previous researchers, which is <2 mg/L (Rohim et al. 2022). Detailed habitat characteristics and water quality in the Alas-Singkil watershed can be seen in Table 3.

The water quality in other rivers in the tropics shows no different values. The rivers upstream and with good forests show better water quality than the downstream areas. Land clearing for plantation activities, especially oil palm, has changed water quality, especially dissolved oxygen, turbidity, and water pH (Luke et al. 2016; Rosli et al. 2020). This also happens at research locations where there is a lot of land clearing for plantations downstream, where the pH of the waters tends to be lower, and the water is more turbid.

Figure 2. River conditions in the downstream section of the Alas-Singkil Drainage Basin, Northern Sumatra, Indonesia. A. Estuary; B. Downstream; C. Lake; D. Singkil swamp forest; E. Oil palm canal; F. Swamp

Species richness and distribution of nekton

During the observations in the Alas-Singkil watershed, a total of 99 fish species (39 Family), as well as 9 shrimp species and 1 freshwater crab species, 1 freshwater turtle species, and 1 crocodile species were collected (Table 4-5). In addition to fish, 5 species of freshwater shrimp from Atyopidae and Palamonidae were also found in the upstream, middle, and downstream parts. The most common freshwater shrimp found in Indonesia are members of the family Palaemonidae and Atydae (Wowor et al. 2004). However, Atyopidae shrimp are only found in the middle part, with characteristics of rocky and gravel waters and swift and steep currents. The genus Macrobranchium sp. is almost always found in every segment of the Alas-Singkil watershed. Macrobranchium is a freshwater-dwelling crustacean where Macrobranchium can be found in flowing and stagnant water (Desrita et al. 2018; 2020; 2022). In addition, its entire life cycle is in freshwater (Wowor et al. 2004). Other aquatic organisms in the Alas-Singil watershed are freshwater crabs and freshwater turtles in the upper reaches of the creeks. Meanwhile, in the lower to middle reaches and in some swamps, populations of estuarine crocodiles (*Crocodylus porosus*) are found.

Figure 3. River conditions in the middle stream section of the main river (sand and gravel substrate)

Figure 4. River conditions in the middle stream section of the Alas-Singkil watershed, Northern Sumatra, Indonesia (other than the main river) (substrate of sedimentary rock, fast currents, and narrow)

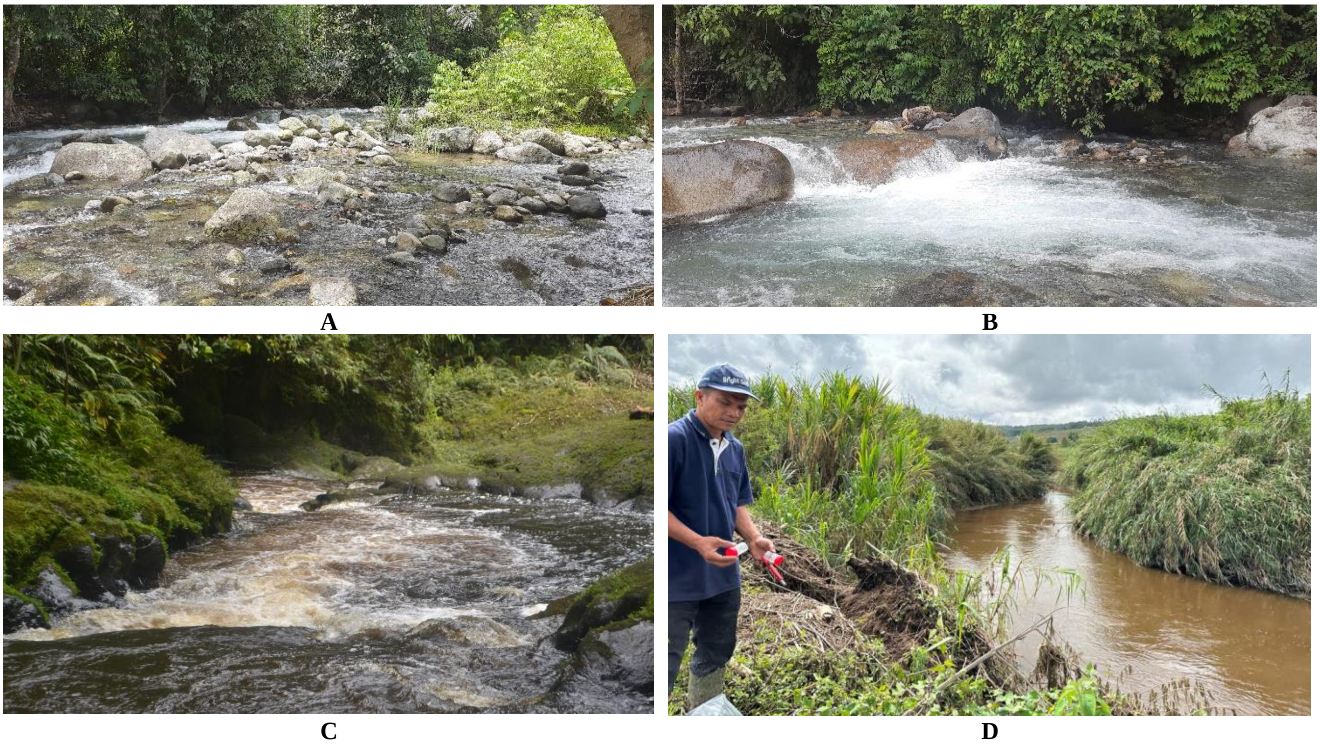

Figure 5. River conditions in the upstream section. A-B. Rocky substrate and clear water in the upper reaches of the main river; C. Sedimentary rock substrates in the Simonggo, Lae Kombih, and Lae Renun sub-watersheds; D. A small part of the other upstream river sand and gravel substrate

The nekton found in the Alas-Singkil watershed is higher than in other watersheds in Indonesia. Desrita et al. (2020) found 68 nekton species in the Batangtoru Watershed (North Sumatra). Wampu Watershed (North Sumatra) found 50 nekton species (42 individuals) (Muhtadi et al. 2017; Putri et al. 2017; Desrita et al. 2018). Only 21 freshwater fish species were found in the Serayu Basin, Central Java, Indonesia (Suryaningsih et al. 2020). The richness of fish species in the Martapura River and its surroundings (West Kalimantan) was also only found in 35 species (Rusmilyansari et al. 2021). On the Cisadea River, West Java (Indonesia) found 48 species (Paujiah et al. 2019). In various watersheds in the Asian region, it shows lower levels, such as in the Tandag watershed, Surigao del Sur, Philippines, only 23 species of fish were found (Ojao et al. 2021), 84 species in The Ganjiang River (Hu et al. 2019), only 23 species were found in the Irtysh River and Ulungur River basins in Xinjiang, China (Li et al. 2020), in West Bengal and Madhya Pradesh 71 and 69 species, respectively (Mondal and Bhat 2020), and 76 species in the Baleh River Basin in Sarawak, Borneo (Soo et al. 2021). However, it was higher in the Gangga River, with 143 freshwater fish species (Sarkar et al. 2012), in the Guangxi Watershed, China, reaching 142 freshwater fish (He et al. 2022). The highest richness of fish species is found in the Yangtze basin, where 361 species are found; 177 endemic species, and 25 are categorized as endangered (Huang and Li 2016).

Discussion

Nekton spatial distribution

In general, the richness of nekton species in the Alas-Singkil watershed is found more in the lower than in the middle and upper reaches of the river. At least 56 species (50%) were found in the downstream section, and 23 species (21%) and 28 species (25%) in the middle and upstream sections, respectively (Figure 6).

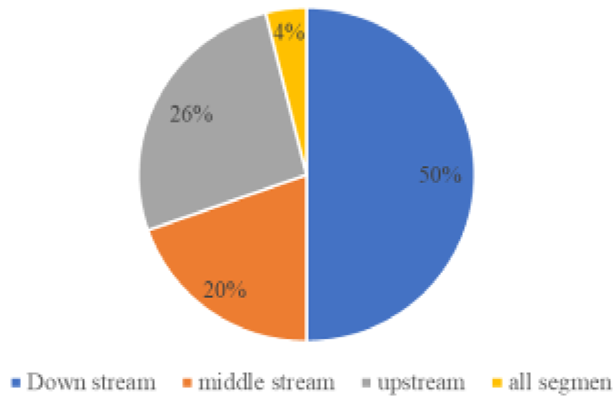

Figure 6. Percentage of the number of species found per river segment in the Alas-Singkil watershed, Northern Sumatra, Indonesia

Table 3. Habitat conditions at the study site

Environment parameter	Location						
	Estuary	**Downstream (main river)**	**Downstream (main tributary/ Simonggo)**	**Downstream (main tributary/ Lae Kumbi)**	**Downstream (main tributary/ Lae Batu)**	**Downstream (main tributary/ Lae Pangkahan)**	**Downstream (Main tributary/ Lae Renun)**
Land use	Swamp forest and settlements	Swamp forest, oil palm plantations, settlements	Oil palm plantation	Oil palm plantation	Oil palm plantation	Settlements and farm	Farm
River slope	Ramps	Ramps	Steep	Slightly steep	Ramps	Steep	Ramps
Substrate	Sand and mud	Silty sand	Silty sand	Silty sand	Silty sand	Sand, silty sand	Gravel and stones
Depth (m)	1.0-3.5	1.02.35	1.0 - 2.8	1.0 - 2.5	1.0-2.5	1.0-2.5	1.0-3.0
Wetted river (m)	300-350	350-400	120-130	25-30	60-65	60-75	25-35
River width (m)	500-600	300-360	130-135	30-40	65-70	60-80	30-40
Flow (m/s)	0.1-1.5	0.1-1.5	0.1-1.5	0.1-1.5	0.1-1.5	1.0-1.7	0.5-1.9
	0.5	0.7	0.75	0.75	0.70	0.8	1.1
Visible color	Brownish cloudy	Brownish cloudy	Brownish cloudy	Brownish cloudy	Brownish cloudy	Brownish cloudy	Brownish cloudy
Water transparency	0.30	0.55	0.50	0.55	0.6	0.6	0.7
Turbidity NTU)	21.31-26.74	28.55-40.98	17.92-24.50	37.84-40.99	22.61-22.79	72-73	36.55-37.80
Temperature (°C)	28.7-30.7	26.7-27.5	27.0-27.3	25.4-25.7	26.1-2.5	24.0-24.5	26.7-27.0
TDS (mg/L)	1498-7079	18-65	238-240	220- 221	388-390	122-124	400-410
Conductivity	1066-1293	36-130	332-340	440 -442	450-460	222-224	560-562
DO (mg/L)	2.4-4.8	6.0-7.9	6.7-7.0	6.5-7.1	6.7-7.3	7.9-8.5	7.5-8.0
pH	6.8-7.3	5.1-6.3	8.0-8.3	7.1 - 7.3	7.-7.5	7.0-7.4	7.5-7.9
Mesohabitat	Pool & run	Pool & run	Pool & run	Pool & run	Pool & run	Pool & run	Pool & Fast run

Table 3. Habitat conditions at the study site (*continued*)

Environment parameter	Location Middle stream (main river)	Middle (main tributary/ Simonggo)	Middle stream (main tributary/ Lae Kumbi)	Middle stream (main tributary/ Lae batu)	Middle stream (main tributary/ Lae Pangkahan)	Middle stream (Main tributary/ Lae Renun)	Middle stream (tributary/ Lae Ordi)
Land use	Farms and settlements	Forests and farm	Farms and settlements	Oil palm plantation	Farms and settlements	Farms, rice fields, and settlements	Farms and settlements
River slope	Ramps	Steep	Steep	Ramps	Steep	Steep	Steep
Substrate	Sand and gravel	Sedimentary rock	Sedimentary rock	Gravel and sand	Sedimentary rock	Sedimentary rock	Sedimentary rock
Depth (m)	1.0-3.0	1.02.35	1.0 - 2.5	0.5 - 1.5	1.0-2.5	1.0-2.5	1.0-2.5
Wetted river (m)	90-100	25-30	25-30	12-15	60-65	60-75	20-30
River width (m)	100-120	30-40	30-35	15-20	65-70	60-80	25-35
Flow (m/s)	0.1-1.5	0.1-1.5	0.1-1.5	0.1-1.5	0.1-1.5	1.0-1.7	0.5-1.9
	0.5	0.7	0.75	0.75	0.70	0.8	1.1
Visible color	Brownish cloudy	Brownish cloudy	Brownish cloudy	Clear	Brownish cloudy	Brownish cloudy	Brownish cloudy
Water transparency	0.30	0.55	0.50	0.55	0.6		
Turbidity NTU)	44.10-44.28	28.55-40.98	17.50-20.20	16.67-14.91	44.72-50.73	30.81-35.71	18.61-20.08
Temperature (°C)	26.4-26.6	26.7-27.5	20.1-20.7	22.1 - 22.7	22.0-22.5	24.7-24.9	19.9-20.1
TDS (mg/L)	90-199	18-65	16-17	20- 21	12-14	56-58	16-20
Conductivity	180-198	36-130	30-32	40 - 42	22-24	104-112	32-40
DO (mg/L)	5.7-7.0	6.0-7.9	8.4-8.8	8.1 - 8.9	8.0-8.5	7.4-8.5	8.4-8.7
pH	7.3-7.6	5.1-6.3	7.5 - 7.7	7.1 - 7.5	7.5-7.7	7.9-8.1	7.5-7.7
Mesohabitat	Pool & run	Rapid & pool	Rapid & pool	Pool & run	Rapid & pool	Rapid & pool	Rapid & pool

Table 3. Habitat conditions at the study site (*continued*)

Environment parameter	**Location**							
	Upstream (main river)	**Upstream (main tributary)**	**Upstream (tributary)**	**Swamp forest area**	**Lake**	**Oxbow lake**	**Palm canal**	**Tributary (*Palm oil plantation*)**
Land use	Forest	Forests and farm	Farm and forests	Swamp forest	Settlements and farm	Oil palm plantation	Oil palm plantation	Oil palm plantation
River slope	Steep and precipitous, with a small portion that is gently sloping	Steep and rugged	Steep and rugged	Ramps	Ramps	Ramps	Ramps	Ramps
Substrate	Rocky and slightly sandy	Rocky	Rocks and gravel	Mud and silty sand	Mud	Mud	Mud	Sand and gravel
Depth (m)	0.5 - 1.0	0.2 - 0.7	0.5-1.5	0.8-4	0.5-10	2.0 - 5.0	1.0 - 1.5	0.2-1.5
Wetted river (m)	4.0-5.0	15.0-20.0	15.0-20.0	-	-	-	3-5	10-15
River width (m)	5.0-10.0	20-25	20.0-30.0	-	-	-	3-5	15-25
Flow (m/s)	0.38-0.50	0.13-0.19	0.22-0.85	0.1-0.3		-	0.05-0.1	0.05-0.7
	0.42	0.15	0.58	0.2	-		0.05	0.1
Visible color	Clear	Clear	Clear	Brownish cloudy	Greenish	Brownish cloudy	Brownish	Brownish
Water transparency	0.3	0.5	1.5	0.8-1.4	1.2	0.9	0.3	0.9
Turbidity NTU)	17.10-18.10	10.46-11.02	11.54 - 11.59	9.34-10.84	8.65-8.78	15.56-16.60	8.62-9.87	9.27-12.23
Temperature (°C)	25.9 - 26.7	24.1-24.3	26.6 - 26.9	25-31	29.0-29.5	30.5-31.0	27.6-28.5	26.1-26.7
TDS (mg/L)	25 -35	21-22	22-23	13-46	168-170	280-282	11-23	10-12
Conductivity	52 - 70	42 - 43	43-46	34-48	136-140	460-466	17-35	20-24
DO (mg/L)	7.4 - 7.8	8.3 - 8.5	8.1-8.4	1-1,8	7.3-7.5	4.4-6.0	0.7-3.8	1.2-6.1
pH	6.7 - 6.9	6.5 - 6.8	7.6-7.8	3,8-4,4	7.0-7.5	6.8-7.0	5.6-6.5	6.4-7.4
Mesohabitat	Fast run & pool	Fast run & pool	Fast run & pool	Pool	Pool	Pool	Pool	Pool

At least only 4 species (4%) of nekton are found in the upstream, middle, and downstream of the river. Blue panchax (*A. panchax*), eel fish (*Anguilla bicolor* and *Anguilla marmorata*), and snakehead (*Channa striata*) are fish that can be found in the lower, middle, and upper reaches of the river. However, overall the nekton that had the highest distribution in the Alas-Singkil watershed based on their availability at the point of observation was *B. binotatus* (49.30%), *A. panchax* (44.19%), and *C. striata* (31.16%). *Barbodes binotatus* has a high distribution in the upper river and tributaries of Alas-Singkil. *Aplocheilus panchax* and *C. striata* are more widely distributed geographically but the occurrence at each location is still lower than *B. binotatus*. Another species that has a fairly wide distribution and found quite a lot of observation points is the mahseer fish. The frequency of occurrence of each mahseer fish was *Neolissochilus sumatranus* at 30.70%, *soro soro* at 29.77%, *Tor tambra* at 30.23%, and *Tor tambroides* at 29.30%. These mahseer fish are widespread in the middle to upper reaches of the river with moderate to strong currents and rocky substrates and sedimentary rocks. Apart from mahseer fish, fish that inhabit fast-flowing waters are Rasborinae, Balitoridae, and Rhyacichthyidae. Sisoridae fish also like fast-flowing waters but are found in tributaries. *Rasbora sumatrana* from Rasborinae also has a high frequency of appearance, reaching 22.79%.

Meanwhile, there is quite a lot of fish that have a limited distribution in the Alas-Singkil watershed. *Mystus punctifer* was found very limited to the Simongo tributary (Simonggo sub-watershed) to be exact, in the Rambe River. *Kryptopterus piperatus*, *Leiocassis aculeata* and *Leiocassis micropogon* were found to be very restricted to the Soraya River in the Subulussalaam (middle part of the main river). *Channa cyanospilos* was found confined to the headwaters of the Lae Renun River (sub-basin of the Lae Renun River). *Clarias microspilus* and *Rasbora bunguranensis* were found very limited to Singkil Swamp Forest.

The number of fish species and populations is generally found more in the downstream section due to the various variations of micro-habitats around it. In the downstream section, in addition to lower currents than in the upstream section, there are swamps and palm channels for various habitats of aquatic organisms that do not like currents. This is as described by Huang et al. (2019), Desrita et al. (2020), and Soo et al. (2021), that the lower reaches of the watershed have a higher number of species and nekton populations than the middle, upper reaches, and tributaries. Differences in the spatial distribution of nekton in the upstream, middle, and downstream segments of the Alas-Singkil watershed indicate that each observation station provides different niches (habitat and food), so the species composition is different. The lower part has wider and more diverse niches due to the presence of swamps around the river. Moreover, the swamp at point 14 is one of the widest swamps in Indonesia. Rawa Singkil Wildlife Reserve is one of the remaining peat swamp forests in Aceh Province (Rohim et al. 2022). Some researchers say that the spatial distribution of species richness is related to differences in habitat and the presence of microhabitats, substrate composition, and water depth (Costa et al. 2013; Hasyimah et al. 2013; Basavaraja et al. 2014; Ohee 2016; Muhtadi et al. 2017; Stegmann et al. 2019; Soo et al. 2021; Caldeira et al. 2023), diversion of water mass for irrigation/hydropower and damage to vegetation around rivers (Kottelat 2016; Soo et al. 2021; Buj et al. 2023).

Indonesian shortfin eel (*A. bicolor*) and Giant mottled eel (*A. marmorata*) of the Anguilidae family were found along the main river from downstream to upstream (Alas sub-watershed). Meanwhile, these eels were not found in other sub-watersheds. This is possible in the presence of natural barriers in the form of bottom waters, which are sharp sedimentary rocks in the middle stream section of the river (Figure 2). In addition, several waterfalls with heights that are difficult for eels to pass. The existence of this eel 'journey' from various environmental conditions, of course, can affect the success and achievement of eels reaching the upstream of the river so that it has the potential to contribute to the decline in eel recruitment. Arai et al. (2013) explained that the farther the eel migration, the lower the eel's productivity. High eel productivity in aquatic conditions with little variation in substrate and flow, highly modified channels, and fewer/no aquatic macrophytes. Furthermore, Tamario et al. (2018), Degerman et al. (2019), and Halvorsen et al. (2020) explain that the chances of the emergence of eels upstream of the river decrease significantly with further distance from the river estuary. The existence of waterfalls and strong currents is one of the natural barriers for an eel to reach the upstream area (Kerr et al. 2016). Furthermore, Kerr et al. (2016) explained that strong currents are a natural barrier hindering fish migration to the upstream part. Adult eel swimming speed is not more than 1.5 m/s; Eels are fish that cannot jump if a waterfall exists. This is considered a natural barrier in the Simonggo, Lae Renun, and Lae Kumbih Rivers, where 2 waterfalls were found with a 3-4 m height. Although the waterfall is low, the most influential presumption of the natural barrier in the study location is the strong current with high and steep rock walls.

Community structure

Alas-Singkil watershed is in the downstream section with a value of 4.39, and the lowest diversity index is in the upstream section with a value of 2.015 (Figure 7). The upstream section with a steep river type and swift currents, so the microhabitat in the upstream section is not diverse (Muhtadi et al. 2017). In such microhabitat conditions, only a small proportion of fish can adapt and settle in steep river types and have swift currents by having modified body shapes and fins in the form of suction pads and distinctive fish lips that enable them to find food. Only Sucking catfish, Masheer, and Barred loach were found in these microhabitat conditions. Downstream, diversity was high due to the presence of several microhabitat variations. Downstream, in addition to lower currents, there are wider riverbanks with many swamps and oil palm plantation channels. Various variations in habitats like this allow various groups of fish to live and develop in the downstream section (Desrita et al. 2020; Mondal and Bhat 2020).

Table 4. Fish species richness in the Alas-Singkil watershed, Northern Sumatra, Indonesia

Family/species	Indonesian name	Local name	Common name	No. of fish caught	Freq. of occur. (%)	Locations (distribution habitats)	IUCN status**
Ambassidae							
Ambassis kopsii	Serinding	Gegge	Singapore glassy perchlet	13	1.40	Downstream, swamp, and estuary	NE
Ambassis nalua	Serinding	Gegge	Scalloped perchlet	17	2.33		LC (20/09/20)
Ambassis urotaenia	Serinding	Gegge	Banded-tail glassy perchlet.	8	1.86		LC(21/09/20)
Anabantidae							
Anabas testudineus	Betok	Corop	Climbing perch	15	2.79	Swamp	LC(10/08/19)
Anguilidae							
Anguilla bicolor	Sidat	Lumpe, Moa	Indonesian Shortfin Eel	5	12.09	Main rivers, tributaries (Alas Sub-basin and	NT(11/08/19)
Anguilla marmorata	Sidat	Dungdung	Giant mottled eel	2	6.51	Lae Gunung), marshes, swamps, and estuaries	LC(06/11/18)
Aplocheilidae							
Aplocheilus panchax	Kepala timah	Kepala timah	Blue panchax	23	44.19	Tributaries and swamp	LC(21/06/18)
Apogonidae							
Apogon hyalosoma	Sirinding	Gegge	Mangrove Cardinalfish	5	1.86	Downstream, swamp, estuary	LC(09/10/20
Bagridae							
Hemibagrus caveatus	Baung	Baung	Catfish	37	6.05	Downstream - middle stream and swamp	NT(01/09/18)
Leiocassis aculeata		Singsing		3	0.93	Middle stream in the main river	DD(10/05/19)
Leiocassis micropogon		Singsing	Bumble Bee Catfish	17	0.93	Swamp and middle stream	LC(07/05/19)
Mystus alasensis	Baung	Singsing	Catfish	25	2.33	Tributaries (downstream)	DD(01/09/18)
Mystus castaneus	Baung	Singsing	Pearl Catfish	28	1.86	Tributaries (downstream)	LC(09/05/19)
Mystus nigriceps	Baung	Baung/ Temabu	Two-spot catfish	33	2.33	Tributaries (downstream) and swamp	LC(08/05/19)
Mystus punctifer	Baung	Temabu	Catfish	3	0.47	Restricted in Simonggo sub-basin	**VU** (15/05/19)
Balitoridae							
Homalopterula ripleyi				27	5.12	Tributaries (upstream)	LC(27/12/18)
Homaloptera weberi				23	4.65	Tributaries (upstream)	DD(28/01/18)
Homaloptera vanderbilti				22	4.65	Tributaries (upstream)	DD(27/12/18)
Belontidaae							
Trichopodus pectoralis	Sepat siam	Siam	Snakestin gourami	3	4.19	Swamp	LC(22/02/12)
Trichopodus trichopterus	Sepat rawa	Capet	Three spot gourami	11	2.79	Swamp	LC(21/01/19)
Butidae							
Oxyeleotris marmorata	Betutu	Seluntok	Marble goby	11	1.86	Middle stream (main river) and lake	LC (24/08/18)
Butis gymnopomus			Striped Crazy Fish	6	1.40	Downstream, swamp, and estuary	LC (23/08/18)
Ophiocara porocephala				5	2.33	Downstream, swamp, and estuary	LC (30/06/18)
Carangidae							
Caranx ignobilis			The giant trevally	1	1.40	Downstream and estuary	LC (09/03/15)
Caranx sexfasciatus		Merah mata	Bigeye Trevally	2	1.40	Downstream and estuary	LC (13/12/18)
Channidae							
Channa gachua	Gabus	Bakok	Dwarf snakehead	5	6.05	Swamp and tributary (middle stream)	LC (23/03/10)
Channa lucius	Gabus	Bujuk	Forest Snakehead	7	5.12	Swamp and tributary (middle stream)	LC (26/11/19)
Channa striata	Gabus	Gabus	Snakehead murrel	12	31.16	Swamp, main river, and tributaries (downstream to upstream)	LC (11/08/19)
Channa cyanospilos	-	-	Striped snakehead	3	0.93	Restricted in upstream Lae Renun	DD (26/11/19)

Cichlidae							
Oreochromis niloticus	Nila	Nila	Nile tilapia	8	3.72	Swamp & tributaries	LC (06/04/20)
Clariidae							
Clarias batrachus	Lele kampung	Lele	Philippine catfish	15	3.72	Swamp & tributaries	LC (16/01/19)
Clarias teijsmanni	Lele	Limbat	Walking catfish	2	2.33	Tributaries	NE
Clarias gariepinus	Lele	Dumbo	North African catfish	1	1.40	Tributaries	LC (20/06/18)
Clarias microspilus	Lele			3	0.47	Singkil Swamp forest	**EN** (01/09/18)
Cyprinidae							
Barbodes binotatus	Keperas	Pora-pora	Spotted barb	57	49.30	Tributaries (upstream)	LC (31/01/19)
Striuntius lateristriga	Wader blang	Pora-pora/ Gaman	Spanner barb	21	11.16	Tributaries (upstream)	LC (27/01/19)
Barbonymus schwanenfeldii	Lemeduk	Lemeduk	The tinfoil barb	11	1.86	Main rivers (middle stream)	LC (09/01/19)
Cyprinus carpio	Mas	Mas	Common carp	3	1.40	Tributaries	VU (01/01/08)
Cyclocheilichthys armatus				31	4.65	Downstream-middle stream, swamp,	LC (13/01/19)
Cyclocheilichthys apogon	Keperas	Sitengkal/ Gar gar	Beardless barb	33	5.12		LC (13/01/19)
Hampala macrolepidota	Sebarau	Hampala/Kelubak	Hampala barb	5	2.33	Downstream-middle stream	LC (01/02/19)
Mystacoleucus marginatus	Cencen	Cencen	Burmese rainbow barb	13	1.40	Main river (middle stream)	LC (21/03/11)
Neolissochilus sumatranus				24	30.70	Middle stream (tributaries)	LC (29/04/20)
Neolissochilus soro	Jurung	Ihan, mera	Masheer	25	29.77	Middle stream (tributaries)	LC (29/04/20)
Oliotius oligolepis	Keperas	Pora-pora/Gaman	Checkered barb	28	1.86	Tributaries (upstream)	LC (24/04/20)
Osteochilus jeruk	Nilem	Lampam	-	44	7.44	Downstream-middle stream, swamp	LC (22/04/20)
Osteochilus serokan	Nilem	Lampam	-	39	8.37		DD (01/02/19)
Osteochilus vittatus	Nilem	Paitan	Bonylip barb	31	9.30	Swamp & tributaries	LC (18/04/20)
Tor douronensis	Jurung	Gemo	Mahseer	22	27.91	Middle stream - upstream (tributaries)	NE
Tor tambroides	Jurung	Gemo	Mahseer	24	29.30	Middle stream-upstream (Tributaries)	DD (01/08/18)
Tor tambra	Jurung	Gemo	Mahseer	23	30.23	Middle stream-upstream (Tributaries)	DD (07/08/18)
Danionidae							
Danio albolineatus	Keperas	Pora-pora	Pearl danio	22	1.86	Middle stream (tributaries)	LC (25/03/11)
Rasbora api	Seluang	Sulum	Rasbora	16	6.98	Middle stream-upstream (Tributaries)	LC (25/11/18)
Rasbora arundinata	Seluang	Sulum	Rasbora	18	6.05	Middle stream-upstream (Tributaries)	LC (07/03/20)
Rasbora bankanensis				16	2.33	Middle stream-upstream	LC (01/02/19)
Rasbora bunguranensis				2	0.93	Singkil Swamp forest	DD (08/03/20)
Rasbora einthovenii				9	0.93	Middle stream-upstream	LC (14/01/19)
Rasbora meinkeni				10	0.93	Middle stream-upstream	LC (09/01/19)
Rasbora sumatrana				22	22.79	Middle stream-upstream (Tributaries)	DD (01/02/19)
Rasbora trunctata	Seluang	Sulum	Rasbora	19	6.51	Middle stream-upstream (Tributaries)	LC (27/12/18)
Gereidae							
Gerres filamentosus				2	2.33	Downstream and estuary	LC (11/16/16)
Gobbidae							
Awaous grammepomus	Belosoh	Lontok	Scribbled goby	3	2.33	Downstream, swamp, and estuary	LC (26/08/18)
Glossogobius aureus			Golden flathead goby	2	1.86	Downstream, swamp, and estuary	LC(26/08/18)
Glossogobius giuris			Tank goby	2	1.40	Downstream, swamp, and estuary	LC(11/08/19)
Periophthalmus argentilineatus			Barred mudskipper	3	3.26	Downstream, swamp, and estuary	LC (20/06/17)
Haemulidae							
Plectorhinchus gibbosus			Brown sweetlips	2	1.40	Downstream, swamp, and estuary	LC (25/08/11)

Helostomatidae							
Helostoma temminckii	Tambakan	Alu	Kissing gourami	4	2.79	Downstream and swamp	LC (19/09/19)
Kuhliidae							
Kuhlia marginata			Dark-margined flagtail	2	3.26	Downstream and estuary	LC (14/02/19)
Leiognathidae							
Leiognathus equula			Common ponyfish	1	2.79	Downstream and estuary	LC (02/07/16)
Loricariidae							
Pterygoplichthys pardalis	Ikan sapu-sapu	Ikan indosiar	Amazone sailfin catfish	15	2.79	Swamp and middle stream in Tributaries	NE
Lutjanidae							
Lutjanus argentimaculatus	Kakap mangrove	Kakap	Mangrove red snapper	2	3.72	Downstream, swamp, and estuary	LC (04/03/15)
Lutjanus fuscescens			Freshwater snapper	1	2.33	Downstream, swamp, and estuary	DD (22/07/20)
Lutjanus russellii			Russell's snapper	1	2.33	Downstream, swamp, and estuary	LC (05/03/15)
Mastacembelidae							
Macrognathus aculeatus	Tilan	Mirik	Lesser spiny eel	9	4.19	Middle stream (Tributaries)	LC (11/12/19)
Macrognathus maculatus	Tilan	Mirik	Frecklefin eel	7	4.19	Middle stream (Tributaries)	LC (12/12/19)
Megalopidae							
Megalops cypronoides			Indo-pacific tarpon	6	3.26	Downstream, swamp, and estuary	DD (29/06/16)
Mugilidae							
Crenimugil seheli			Bluespot mullet	8	3.26	Downstream, swamp, and estuary	LC (02/06/20)
Planiliza subviridis			Greenback Mullet	6	2.79	Downstream, swamp, and estuary	LC (21/08/20)
Nemacheilidae							
Nemacheilus tuberigum	Uceng	Incor	Stone loach	25	26.98	Tributaries (middle-upstream)	**VU (01/07/19)**
Nemacheilus pfeifferae	Uceng	Incor	Barred loach	23	27.91	Tributaries (middle-upstream)	LC (13/05/19)
Oxudercidae							
Pterygoplichthys disjunctivus			Vermiculated sailfin catfish	3	2.33	Swamp	NE
Poeciliidae							
Gambusia affinis			The western Mosquitofish	11	2.79	Upstream (tributaries)	LC (22/01/19)
Poecilia reticulata			The guppy	17	2.79	Upstream (tributaries)	LC (18/05/20)
Pristolepididae							
Pristolepis grooti	Sepatung	Betok, kupar	Indonesian leaffish	5	3.26	Downstream and swamp	LC (08/06/19)
Rhyacichthyidae							
Rhyacichthys aspro	Pasir	Pasir	Loach goby	17	8.84	Middle stream-upstream (Tributaries)	DD (02/01/19)
Siluridae							
Kryptopterus lais				4	1.86	Swamp	LC (27/05/19)
Kryptopterus geminus				3	1.86	Middle stream (main river)	LC (04/04/11)
Kryptopterus piperatus				2	0.47	Middle stream (main river)	**VU (22/05/19)**
Ompok brevirictus	Ompok	Lais		4	1.40	Downstream and swamp	**EN (01/09/18)**
Sisoridae							
Glyptothorax ketambe	Lele gunung	Sating	Sucking catfish	28	3.72	Upstream (tributaries)	DD (04/06/19)
Glyptothorax platypogonides				19	11.63	Upstream (tributaries)	LC (04/06/19)
Glyptothorax plectilis	Lele gunung	Sating		17	4.19	Upstream (tributaries)	**VU (06/06/19)**
Syngnathidae							
Microphis brachyurus		Kuda kuala	Short-tailed pipefish	2	1.40	Downstream, swamp, and estuary	LC (17/01/19)
Soleidae							
Sillago sihama			Sand whiting	3	2.33	Downstream, swamp, and estuary	LC (05/03/15)

Synbranchidae							
Monopterus albus	Belut	Bolut	Asian Swamp Eel.	4	8.37	Swamp and tributaries (middle stream)	LC (10/10/20)
Tetragonidae							
Tetraroge barbata			Bearded rogue fish	3	1.40	Downstream, swamp, and estuary	LC (06/11/20)
Tetrapontidae							
Terapon jarbua			Tiger Perch	5	2.79	Downstream, swamp, and estuary	LC (20/06/16)
Terapon puta			Small-scaled terapon	2	3.26	Downstream, swamp, and estuary	NE
Zenarchopteridae							
Zenarchopterus beauforti				7	2.33	Downstream, swamp, and estuary	LC (16/01/20)

Note: * IUCN (2023) NE: Not Evaluated; DD: Data Deficient; LC: Least Concern; NT: Near Threatened; VU: Vulnerable; EN: Endangered

Table 5. Crustaceans and reptiles found in the Alas-Singkil watershed, Northern Sumatra, Indonesia

Family/species	Indonesian name	Local name	Common name	No. of Fish caught	Freq. of occur. (%)	Locations (distribution habitats)	IUCN status**
Crustacea/Atyidae							
Atyopsis moluccensis	Udang	Udang	Bamboo shrimp	35	9.77	Middle stream (tributaries)	LC(23/11/11)
Atyopsis spinipes	Udang	Udang	Soldier brush shrimp	32	8.84	Middle stream (tributaries)	LC (23/11/11)
Palaemonidae							
Caridina peninsularis			Smooth caridina	7	5.58	Middle stream (tributaries)	LC (28/11/11)
Caridina typus			Typical caridina	10	5.12	Middle stream (tributaries)	LC (17/11/11)
Caridina weberi			Pugnose caridina	11	5.12	Middle stream (tributaries)	LC (21/03/12)
Macrobrachium australe	Udang	Udang	Long-clawed freshwater prawns	12	3.26	Downstream	LC (28/11/11)
Macrobrachium empulipke	Udang	Udang	-	13	2.33	Middle stream (tributaries)	LC (30/11/11)
Macrobrachium lanchesteri	Udang	Udang	Glass shrimp	22	11.16	Middle stream (tributaries)	LC (21/11/11)
Macrobrachium latidactylus	Udang	Udang	Scissor river prawn	27	2.79	Downstream	LC (28/11/11)
Parathelphusidae							
Parathelphusa convexa	Kepiting	Kepiting	Panther crab	4	3.72	Upstream (tributaries)	DD(01/01/08)
Reptile							
Amyda cartilaginea	Bulus	Labi-labi	Asiatic softshell turtle	1	1.86	Upstream (tributaries)	**VU(30/06/00)**
Crocodylus porosus	Buaya	Buaya	Saltwater crocodile	5	7.91	Estuary, swamp, and downstream to middle stream	LC (14/11/19)

Note: * IUCN (2023) NE: Not Evaluated; DD: Data Deficient; LC: Least Concern; NT: Near Threatened; VU: Vulnerable; EN: Endangered

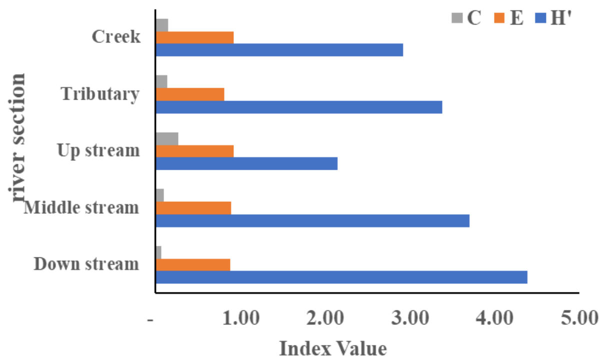

Figure 7. Nekton community structure in Alas-Singkil watershed, Northern Sumatra, Indonesia

The dominance obtained ranged from 0.06-0.26, with the highest value in the upstream section. This dominance value is still relatively low, which is still below 0.5. Previous research results in the Batangtoru watershed with dominance values ranging from 0.10-0.22, with the highest dominance value also found upstream (Desrita et al. 2020). The dominance index value is close to 1 if a certain type or species dominates the community, and if the dominance index is close to 0, no type or species dominates (Odum and Barrett 2005).

The similarity of nekton in the Alas-Singkil watershed obtained based on several other river basins in Indonesia is moderate to high, ranging from (0.88-0.93). This can also show that although many species are found does not mean diversity is high; several factors determine, namely the proportion of each species affects the diversity index (Odum and Barrett 2005). The diversity of the Nekton community will be higher as habitat heterogeneity increases. Heterogeneity includes river width and depth (Muhtadi et al. 2017; Desrita et al. 2018, 2020; Huang et al. 2019).

Management of the Alas-Singkil watershed area

In connection with the Alas-Singkil watershed area is very potential to be used as a good source of hydroelectric energy or Micro hydro/Mini hydro Power Plant (MHP), it is necessary to conduct in-depth studies related to habitat types and migration patterns of ichthyofauna representing 2 seasons, namely the rainy and dry seasons. A temporary assumption is that if water damming is carried out in one particular segment, it will cause habitat fragmentation. This will disrupt fish's spatial and temporal distribution after and before the dam (Barbarossa et al. 2020; Cutler et al. 2020; Liu et al. 2022). For example, constructing the Mrica Reservoir (Central Java) caused habitat fragmentation in the Serayu River, resulting in genetic variation in javean barb fish. Javean barb inhabiting the lower zone of the reservoir form a separate cluster from one inhabiting the reservoir and upper zone of the reservoir, characterized by the presence of cytosine base (C) in the lower zone compared to other zones (Bahiyah et al. 2013). This can disrupt fish populations and communities in river waters (Fuller et al. 2015; Franklin et al. 2022). Another study in Australia found that large dams were a major barrier to the platypus (*Ornithorhynchus anatinus*) movement in Eastern Australian rivers. These barriers have also resulted in gene flow restrictions between the lower and upper parts of the dams (Mijangos et al. 2022). Therefore, in river damming, it is necessary to establish fish runway technology that connects fish populations and communities before and after the dam. In this case, especially fishes that migrate longitudinally between downstream and upstream, such as eels and Mahsser fish and other fishes that migrate from downstream to upstream or vice versa.

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