BIODIVERSITAS
Volume 24, Number 12, December 2023
Pages: 6661-6674

ISSN: 1412-033X
E-ISSN: 2085-4722
DOI: 10.13057/biodiv/d241228

The diversity, distribution, biomass, and conservation status of ichthyofauna of the Singkil peat swamp in Aceh Province, Indonesia

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Manuscript received: 23 October 2023. Revision accepted: 23 December 2023.

Abstract. *Razi NM, Nasir M, Khalidin K, Savira D, Najmi I, Mahfud M, Dermawan F, Fadli N, Muchlisin ZA. 2023. The diversity, distribution, biomass, and conservation status of ichthyofauna of the Singkil peat swamp in Aceh Province, Indonesia. Biodiversitas 24: 6661-6674.* The land conversion of the Singkil peat swamp into oil palm plantations poses a significant threat to the aquatic ecosystem, with potentially detrimental consequences for fish biodiversity. Several reports showed that there was no data on fish diversity in the Singkil peat swamp despite the damage occurring in the area. Therefore, this study aimed to analyze the diversity, distribution, biomass, and conservation status of Ichthyofauna in the Singkil peat swamp waters. Sampling was carried out at 13 locations from July 2023 to August 2023, and the samples were caught using gill nets, casting nets, fishing rods, and traps. A total of 934 samples were collected during the sampling, belonging to 39 species, 31 genera, and 26 families. The results showed that Cyprinidae was the most dominant family, with an average diversity index of 1.23, indicating the medium category. The average dominance index was 0.42, which was placed in the low category. *Channa striata* (Bloch, 1793) and *Trichopodus trichopterus* (Pallas, 1770) had the highest frequency of occurrence and were found in seven locations out of 13 surveyed. Furthermore, these species were categorized as frequently found based on their availability. The average fish biomass was 288.75 kg/ha, with *C. striata* having the largest value. Among the 39 fish species obtained, 3 species were classified as near threatened, including *Anguilla bicolor* (McClelland, 1844), *Mystus bimaculatus* (Volz, 1904), and *Kryptopterus minor* (Roberts, 1989), while 1 invasive sample was recorded, namely *Oreochromis niloticus* (Linnaeus, 1758) in one location.

Keywords: *Channa striata*, fish biomass, fish diversity, invasive species, species richness

INTRODUCTION

Peat swamps are formed by the accumulation of organic material derived from plants, which is then partially decomposed and trapped in water (Hapsari et al. 2022; Wilson et al. 2022). Indonesia has a potential peat swamp area of approximately 34.12 million ha, with 9.6 million ha and 338,164 ha of this expanse being situated on the island of Sumatra and Aceh province, respectively (Ministry of the Environment and Forestry of the Republic of Indonesia 2020). In Aceh Province, a substantial portion of the peat swamp is located on the south-west coast. Furthermore, one of the most expansive areas, known as the Singkil peat swamp, spreads across Aceh Singkil and South Aceh Regencies. The total coverage of the region extends to 102,500 ha, with approximately 81,802.22 ha designated as wildlife reserve areas (Onrizal and Maulana 2020; Rohim et al. 2022). However, unfortunately, the peat swamp ecosystem in Aceh is highly threatened (Djufri et al. 2016). Several studies identified the major factors affecting peat swamps in Aceh and Indonesia, including deforestation, land conversion to palm oil plantations and settlements, and fire forests during the dry season (Muchlisin et al. 2015a; Thomy et al. 2018; Ruysschaert and Hufty 2020). These factors have triggered a marked decline in the area's natural germplasm wealth, leading to a significant reduction in biodiversity.

Peat swamp is known to have a high potential for fish diversity, but there are limited studies on the presence of Ichthyofauna in the area. At present, There were two reports from Malaysia, i.e., in the Kampung Yak Yah peat swamp, Terengganu, West Coast of Peninsular Malaysia, which reported 14 species of fish and is the first report of peat swamp fish species in the area (Hussin-Jasmin et al. 2021), and in the peat swamp in North Selangor, Malaysia, which recorded nine fish species (Saadu et al. 2021). There are only four related reports from Indonesia, including Paada et al. (2022) on Mempawah and Duri River peat swamp, West Kalimantan, which reported six species from both areas. Furthermore, Santoso and Wahyudewantoro (2019) focused on the Arut Lamandau-Kumai River delta, Central Kalimantan, where 95 species of freshwater fish

were found, representing 50 genera, with *Osteochilus* and *Rasbora* being dominant. Thornton et al. (2018) studied peatlands of the Sebangau, Central Kalimantan, and recorded the presence of 43 species, and Suyatna et al. (2021) studied the ichthyofauna in the peat swamp waters of Central Mahakam, Kutai Kartanegara, in East Kalimantan. They recorded 50 species of fish, where Cyprinidae is predominant in terms of total species and individuals. Muchlisin et al. (2015a), in the Tripa Peat Swamp, Aceh, recorded 73 species of freshwater fish, where *Puntius brevis* (Bleeker, 1849) was the most dominant, and three non-native i.e., *Trichopodus pectoralis* (Regan, 1910) or known as *siamese gourami*, *Oreochromis niloticus* (Linnaeus, 1758) and *Pterygoplichthys pardalis* (Castelnau, 1855). The results indicated that ichthyofauna diversity in the Singkil peat swamp had never been studied.

The conservation status of fish inhabiting these areas remains largely unexplored. Indonesia, renowned as a mega-biodiversity country, ranks second only to Brazil in terms of rich biodiversity (Muchlisin et al. 2017). It is estimated that Indonesia is home to approximately 4,197 species, constituting 18% of the world's total fish species. Among these, a total of 1,256 species inhabit freshwaters, with approximately 553 being endemic (IUCN 2023). Freshwater fish in Indonesia are currently facing imminent threats from ecological disturbances, climate change, and the introduction of non-native fish species (Muchlisin 2013; Shackleton et al. 2018; Macusi et al. 2020; Zadereev et al. 2020). According to IUCN data 2023, one species of freshwater species in Indonesia, namely *Chitala lopis* (Bleeker, 1851), has already gone extinct, while 50 and 76 are categorized as endangered and critically endangered, respectively, including the depik *Rasbora tawarensis* (Weber & de Beaufort, 1916) the endemic fish species in the Lake Laut Tawar (Muchlisin et al. 2015b; Muchlisin et al. 2018). Peat swamp is characterized by black and acidic water, which is rich in organic matter (Bate et al. 2017; Lew et al. 2019), making it a unique habitat. Previous reports showed that the ecosystem has been degrading and increasing over the years (PIU-SERT 2013), thereby threatening biodiversity. Information on the diversity, distribution, and conservation status of fish is crucial to be documented as a basis data for planning fisheries resource management policies. Therefore, this study aims to inventory Ichthyofauna and analyze the distribution and conservation status of fish from the area.

MATERIALS AND METHODS

Study area

This study was carried out from July to August 2023 in the Singkil peat swamp, covering two districts, South Aceh and Aceh Singkil, as shown in Figure 1. The sampling site was purposefully determined based on information from local people. Therefore, the sampling was carried out at 13 locations, namely Alur Seunuebuk, Ie Meudama, Teupin Tinggi, Padang City, Krueng Impadang, Kuala Baru Laut, Kilangan Village Harbor, Seunabok Jaya AFD 5, Seunabok Pusaka AFD 4, Seunabok Pusaka AFD 1, Raket Village, Buloh Seuma, and Suka Jaya. The scenery and descriptions of the locations are presented in Table 1 and Figure 2. The identification process was performed at the Fish Hatchery and Breeding Laboratory, Faculty of Marine Affairs and Fisheries, Universitas Syiah Kuala.

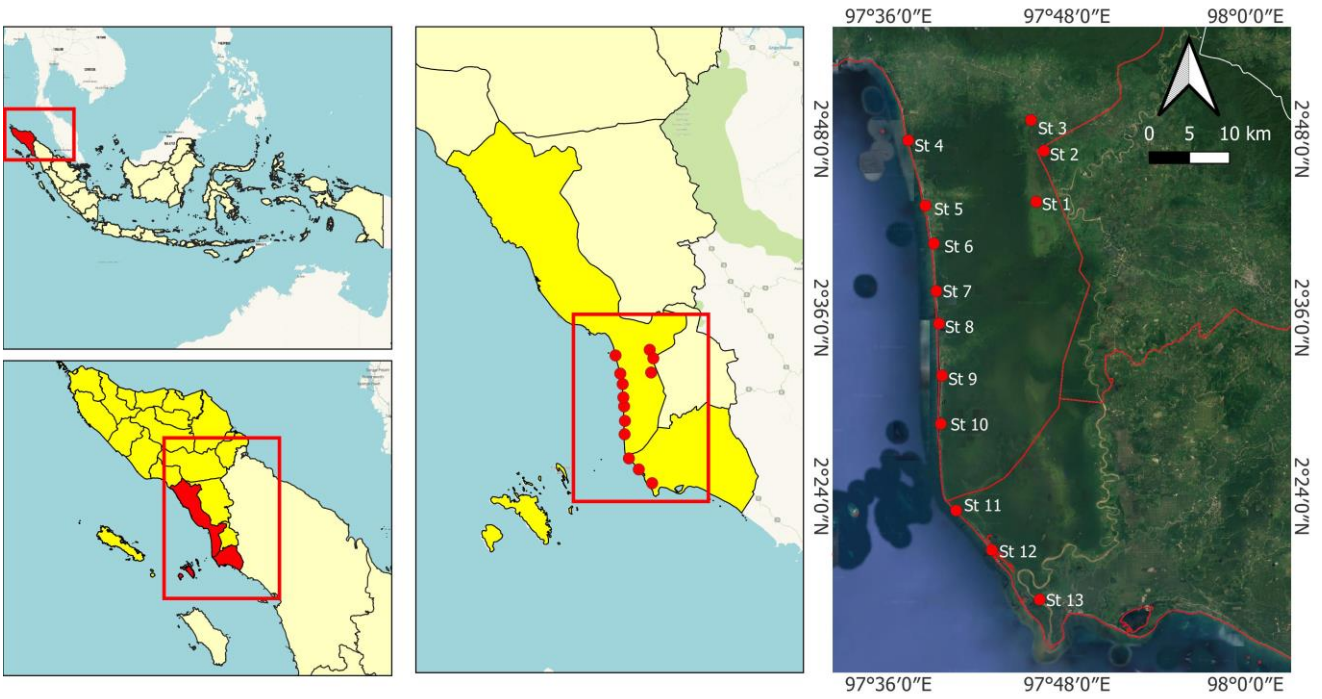

Figure 1. The map of Singkil peat swamp area, Aceh Province, Indonesia, showing the sampling locations (in red dots)

Table 1. The GPS coordinate and general descriptions of the sampling location

Location code	Location name	GPS coordinates	Descriptions	Temperature ± sd (°C)	Do ± sd (mg/L)	Ph ± sd	Salinity ± sd (ppt)
St. 1	Seunabok Jaya AFD 5	2°43'47.00"N, 97°45'56.00"E	Freshwater are, a small river in the oil palm plantation area, is freshwater, and the water is black	31.0 ± 1.00	4.4 ± 0.20	6.5 ± 0.20	0
St. 2	Seunabok Pusaka AFD	2°47'12.70"N, 97°46'27.80"E	A small river in the oil palm plantation area is freshwater, and blackish brown water	31.5 ± 1.32	4.3 ± 0.10	6.7 ± 0.20	0
St. 3	Seunabok Pusaka AFD	2°49'16.40"N, 97°45'35.30"E	The canal in the ASN company's oil palm plantation is freshwater characterized by blackish-colored water with a strong water flow	28.2 ± 0.72	4.4 ± 0.46	6.9 ± 0.10	0
St. 4	Alur Seunuebuk	2°47'55.10"N, 97°37'19.60"E	The river mouth is closed by sand dunes and has the characteristics of brackish water (lagoon). The sand bar breaks during the rainy season, so the river mouth is open; however, the river mouth was closed at the time of sampling	29.0 ± 1.32	5.6 ± 0.36	7.5 ± 0.20	9
St. 5	Ie Meudama	2°43'31.90"N, 97°38'29.00"E	The river estuary is influenced by tides and has characteristics of brackish and blackish water. The mangroves are growing in several parts of the river. There is a traditional fish landing near the sampling location	28.9 ± 0.96	4.1 ± 0.10	6.8 ± 0.26	0
St. 6	Teupin Tinggi	2°40'58.80"N, 97°39'3.30"E	The estuary of the river has fresh water with black, acidic water fresh and water characteristics, and in some parts is overgrown with mangroves that are rich in organic matter.	28.6 ± 1.18	3.9 ± 0.20	4.6 ± 0.10	0
St. 7	Kota Padang	2°37'47.30"N, 97°39'13.10"E	The estuary of the Kuta Padang River is strongly influenced by freshwater. The estuary was receding at the time of sampling. Around the location, there is mangrove growth	28.6 ± 0.89	4.7 ± 0.26	7.1 ± 0.26	0
St. 8	Krueng Impadang	2°35'36.30"N, 97°39'24.10"E	The river mouth is closed by sand dunes and has the characteristics of brackish water. The sand bar breaks during the rainy season, and the river mouth is closed at the time of sampling	28.6 ± 0.53	5.1 ± 0.17	6.7 ± 0.17	2
St. 9	Desa Raket	2°32'6.42"N, 97°39'36.19"E	Freshwater, and the river mouth is covered by sand dunes. The sand bar breaks during the rainy season, and the river mouth is closed during the sampling	28.8 ± 0.72	5.2 ± 0.20	6.6 ± 0.17	0
St. 10	Buloh Seuma	2°28'52.10"N, 97°39'31.30"E	The water has characteristics of black, acidic and fresh water. The mangrove is growing in some parts of the water that are rich in organic matter.	30.0 ± 0.50	4.5 ± 0.36	6.7 ± 0.20	0
St. 11	Suka Jaya	2°23'2.77"N, 97°40'33.20"E	Freshwater, and the mangrove is growing in some parts of the water	28.6 ± 0.40	4.1 ± 0.17	5.3 ± 0.20	0
St. 12	Kuala Baru Laut	2°20'23.10"N, 97°42'57.30"E	Brackish water and mangroves are growing in some parts of the estuary	28.9 ± 0.17	5.9 ± 0.10	6.8 ± 0.20	2
St. 13	Kilangan Village Port	2°17'3.80"N, 97°46'10.10"E	Brackish water, and the water is strongly affected by tide	33.5 ± 0.30	6.8 ± 0.07	8.7 ± 0.20	22

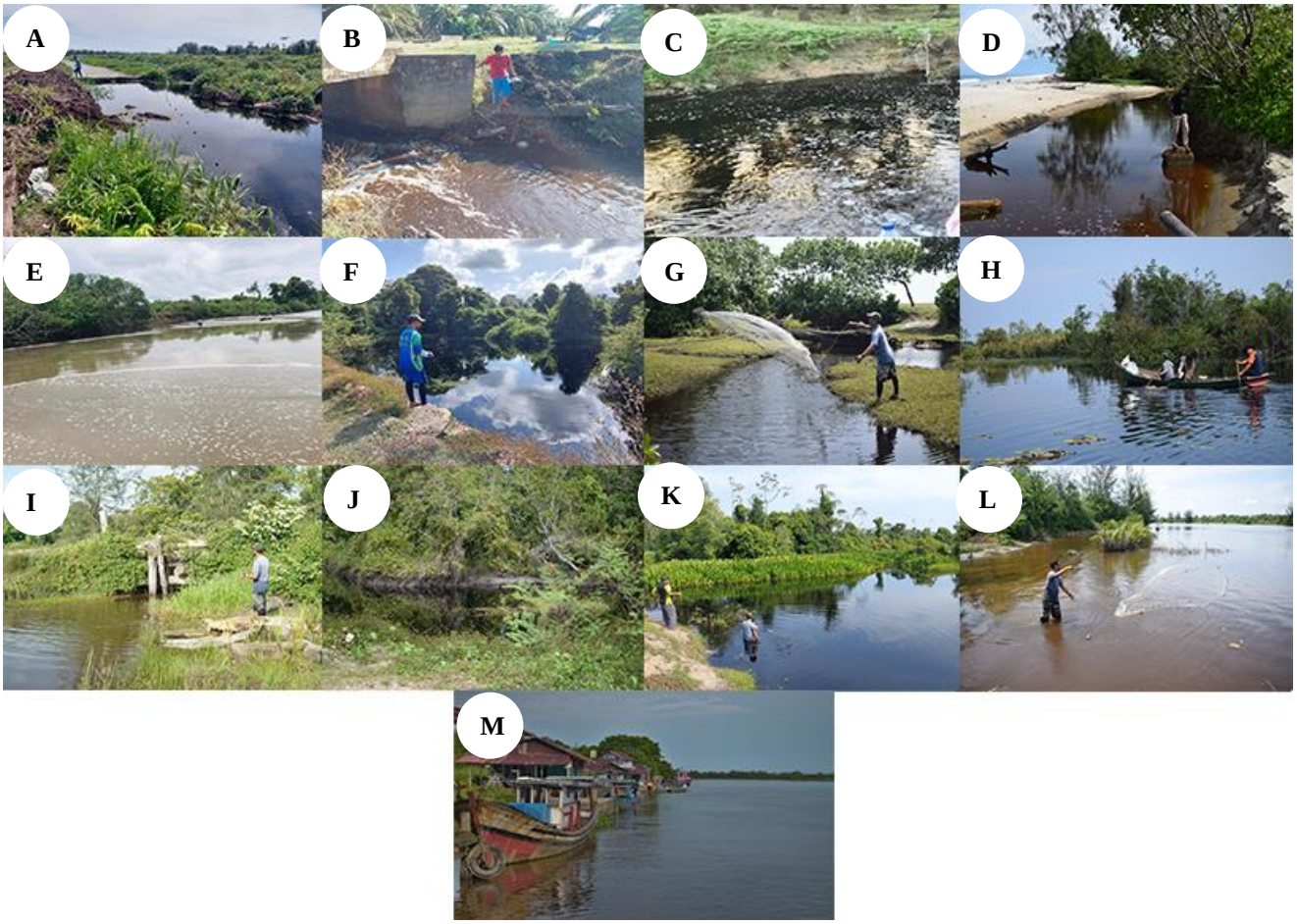

Figure 2. The scenery of sampling locations in Singkil peat swamp waters, Aceh Province, Indonesia: A. Seunabok Jaya AFD 5; B. Seunabok Pusaka AFD 4; C. Seunabok Pusaka AFD 1; D. Alur Seunuebuk; E. Ie Meudama; F. Teupin Tinggi; G. Kota Padang; H. Krueng Impadang; I. Desa Raket; J. Buloh Seuma; K. Suka Jaya; L. Kuala Baru Laut; and M. Kilangan Village Port

Procedures for preservation and identification

The fish sample was caught using gill nets (mesh sizes 1 inch, 1.5 inches, and 2 inches), fishing rods, and traps. The sampled fish was cleaned, photographed for documentation, placed in a plastic bag, and temporarily preserved with crushed ice (4^{o}C) in an icebox. The local name and number of the sample were then recorded. Subsequently, the water quality, including temperature (Thermometer glass ASTM 12C), pH (Atago DPH-2 ATC), dissolved oxygen (DO9100 Dissolved Oxygen Analyzer), and salinity (Atago MASTER-S/ Mill M), were measured at the time of sampling. The fish was identified based on meristic and morphometric characteristics, referring to FishBase (2023).

Community structure

Frequency of occurrence (FO)

The frequency of occurrence of the species was measured as follows (Muchlisin et al. 2015a):

Frequency of occurrence (%) = (The number of locations where a species occurred)/ (Total sampling locations) × 100

Where: The FO was divided into three categories, namely 0-25%: very rarely, 26-50%: rarely, 51-75%: often, and >75%: very often.

Shannon-Weiner diversity index (H')

The Shannon-Weiner diversity index was calculated as follows (Krebs 1989):

$$H' = -\sum \left(\frac{ni}{N}\right) Ln \left(\frac{ni}{N}\right)$$

Where:

ni : Total number of individuals of species-I,

N : The total number of individuals of all species. The Shannon-Wiener diversity index was divided into three categories, including H'≤1, low diversity; 1<H' ≤3, moderate diversity; and H'≥3 high diversity.

Margalef species richness index (d)

The Margalef species richness index was measured as follows (Magurran 1988):

$$d = \frac{S - 1}{\ln N}$$

Where:
S : Total species found
N : Total individuals of all species. The index was divided into three categories, namely d<2.5 low, 2.5<d<4.0 moderate, d>4.0 high

Simpson Dominance Index (d)
The Simpson dominance index was measured as follows (Magurran 1988):

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

Where:
ni : Total individual of species-I
N : Total individual of all species. The Simpson dominance index was divided into three categories, namely low category, 0<d ≤0.5; moderate category, 0.5<d≤0.75, and high category, 0.75<d≤1.0.

Sorensen similarity index (SI)
The Sorensen similarity index was calculated as follows (Brower et al. 1998):

$$SI\ (\%) = \frac{2C}{A+B} \times 100$$

Where:
A : The total species at location A
B : The total species at location B
C : The total species of the same species at locations A and B. The similarity index value ranged from 0 to 100% in four categories, namely: <25% (very dissimilar), 25-50% (not similar), 50-75% (similar), and 75-100% (very similar). This value was calculated using the Paleontological Statistics software (PAST 4.13).

Fish biomass
Fish biomass was calculated by estimating the fork length, followed by conversion into the weight (kg) using the formula of the length-weight relationship of the species, as follows (Kulbicki et al. 2005):

$$W = aL^b$$

Where:
W : Fish biomass (kg/ha)
L : Estimated fish fork length (cm),
a/b : Constant value of fish species. The a and b values were obtained from the FishBase (2023).

Conservation status
The conservation status of the valid species was confirmed by accessing the IUCN Red List database at https://www.iucnredlist.org/ (IUCN 2023), where the invasiveness status was assessed based on IUCN Global Invasive Species Database (http://www.iucngisd.org/gisd/).

Data analysis
The data were presented in tables and figures, then analyzed descriptively by comparing the findings with relevant references, reports and theory.

RESULTS AND DISCUSSION

Species composition, frequency of occurrence and conservation status
A total of 934 fish samples were successfully caught in the Singkil peat swamp, belonging to 26 families, 31 genera, and 39 species(Table 2). The results showed that Cyprinidae was the most dominant family in all locations, followed by Osphronemidae and Ambassidae (Figure 3). Cyprinidae also had the highest number of species (7 species), while Ambassidae, Lutjanidae, Channidae, Gerreidae, Gobiidae, Haemulidae, and Mugilidae each had 2. Meanwhile, the other 18 families in this study had 1 species. Based on the sampling location, Alur Seuneubok (St. IV) had the highest number of species (15 species), while Teupin Tinggi (St. VI) had a lower number, namely two.

Channa striata (Bloch, 1793) and *Trichopodus trichopterus* (Pallas, 1770) had the highest frequency of occurrence as they were observed in 7 locations (FO= 53.85%) and categorized as often found. This was followed by *Ambassis miops* (Günther, 1872) and *Clarias batrachus* (Linnaeus, 1758), each occurring at five locations (FO 38.46%) and classified as rarely found. Meanwhile, the other four species, namely *Cyclocheilichthys armatus* (Valenciennes, 1842), *Gerres longirostris* (Lacepède, 1801), *Osteochilus vittatus* (Valenciennes, 1842), and *Puntius brevis* (Bleeker, 1849) were observed in four areas (FO = 30.77%) and placed in the rare category. The other 31 species were categorized as very rare (<25%), as shown in Figure 4.

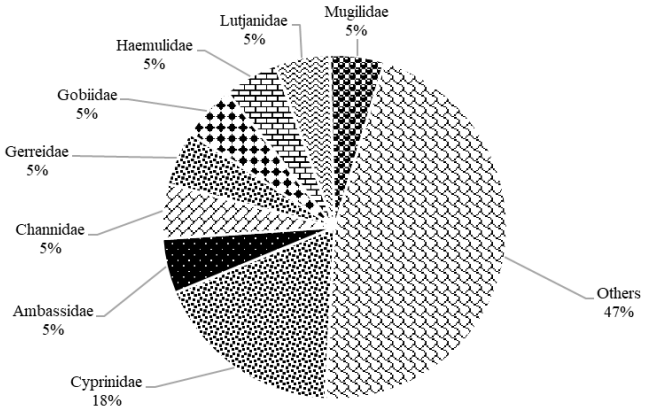

Figure 3. The composition of the fish sample according to family

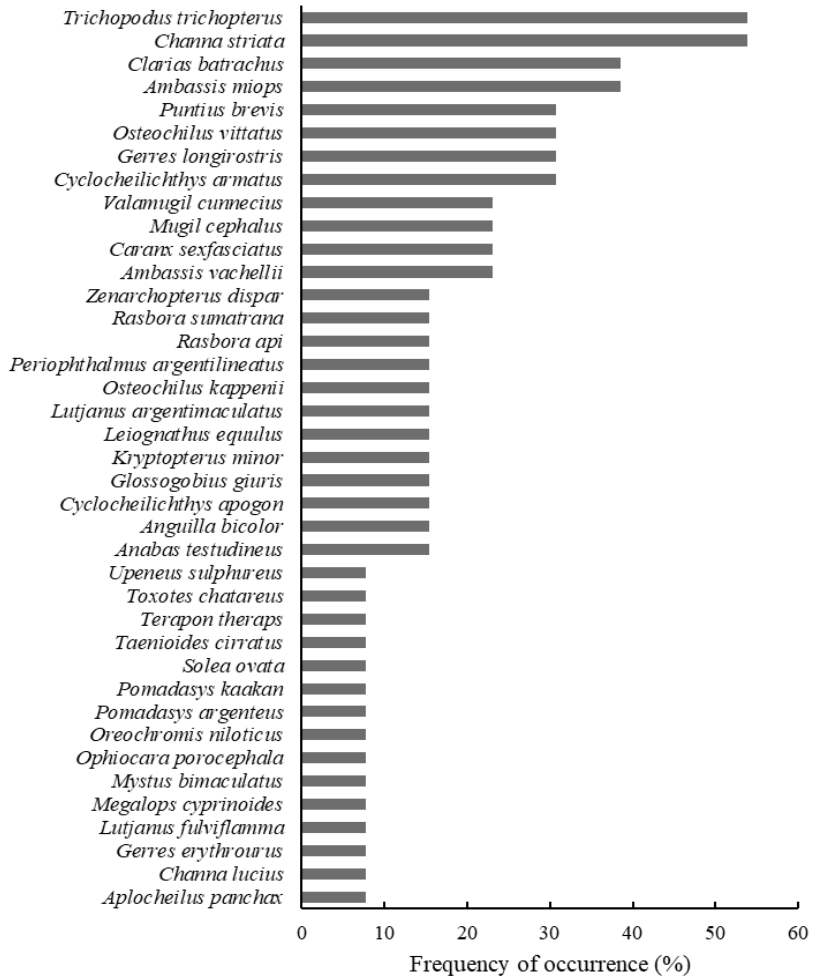

Figure 4. The frequency of occurrence of fish within 13 sampling locations in Singkil peat swamp waters, Aceh Province, Indonesia

Figure 5. Fish species belong to the families Ambassidae, Anabantidae, Anguillidae, Aplocheilidae, Bagridae, Clariidae, and Channidae in the Singkil peat swamp, Aceh Province, Indonesia

Figure 6. Fish species belong to the families Cyprinidae and Carangidae in the Singkil peat swamp, Aceh Province, Indonesia

Figure 7. Fish species belong to the families Gerreidae, Cichlidae, Leiognathidae, Lutjanidae, and Gobiidae in the Singkil peat swamp, Aceh Province, Indonesia

Among the 39 fish species that were successfully collected, 3 species were found in the near threatened category i.e., *Anguilla bicolor* (McClelland, 1844), *Mystus bimaculatus* (Volz, 1904), and *Kryptopterus minor* (Roberts, 1989), 32 species had the status of least concern, 3 species had the status of data deficient, and 1 species was not evaluated. Furthermore, 1 invasive species was recorded during the study, namely *O. niloticus*. The photographs of the fish species are presented in Figures 5-9. Based on the population trends of the 39 fish species collected, 3 species displayed a declining population, namely *Caranx sexfasciatus* (Quoy & Gaimard, 1825), *Kryptopterus minor* Roberts, 1989, and *Mystus bimaculatus* (Volz, 1904); 13 species had a stable population and 23 species had an unknown population status (Table 2).

Figure 8. Fish species belong to the families Megalopidae, Mugilidae, Bagridae, Siluridae, Eleotridae, and Haemulidae in the Singkil peat swamp, Aceh Province, Indonesia

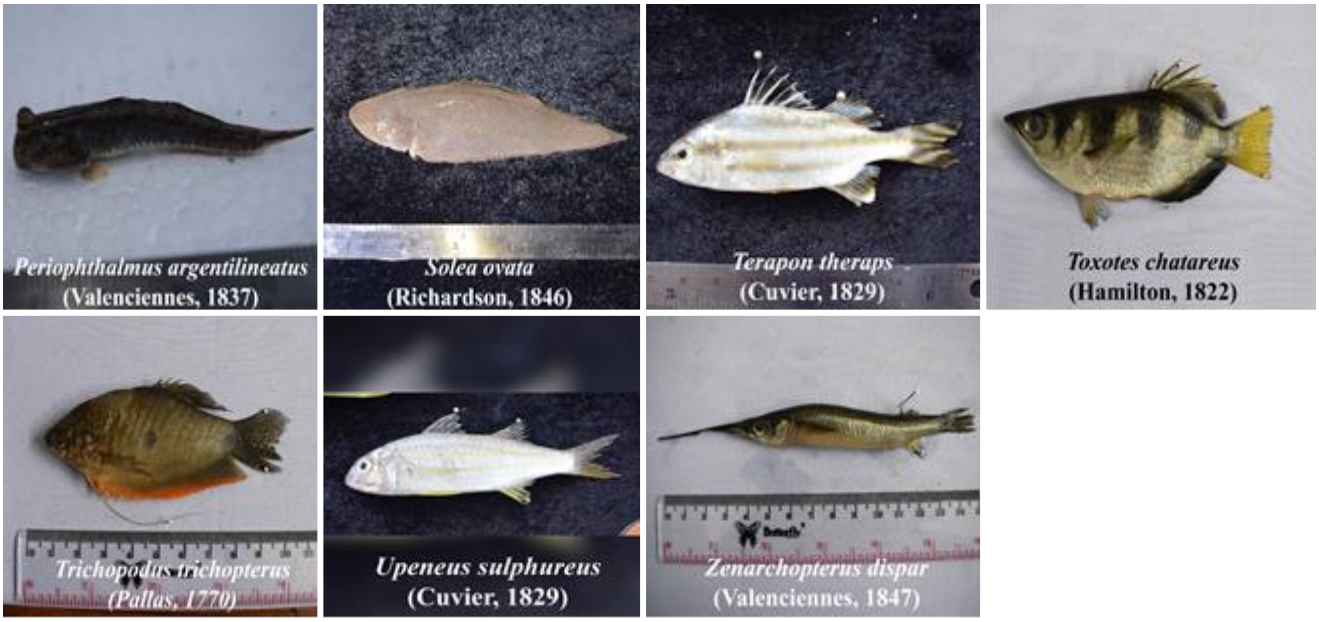

Figure 9. Fish species from the families Oxudercidae, Soleidae, Terapontidae, Toxotidae, Osphronemidae, Mullidae and Zenarchopteridae in the Singkil peat swamp, Aceh Province, Indonesia

Community structure

The Shannon-wiener diversity index in the Singkil peat swamp ranged from 0.15 to 1.80, indicating low to medium categories. Furthermore, an average value of 1.23 was obtained, indicating the medium category, as shown in Table 3. Based on the sampling location, the highest diversity index was found in St. II (Seunabok Pusaka AFD 4) with a value of 1.8, which was classified as medium. The average dominance index (D) in all sampling stations was 0.42, showing a low category. *T. trichopterus* was the most dominant species, followed by *Rasbora api* Lumbantobing, 2010. The results showed that its richness index ranged from 0.37 to 2.61, indicating low to medium classes. The similarity index between the study locations ranged from 0 to 72.73%. The fish community structure at St. IX (Desa Raket) and St. XI (Suka Jaya) were highly similarity compared to other areas, as shown in Figure 10.

Table 2. List of fish species and their occurrence in the Singkil peat swamp, Aceh Province, Indonesia

Family	Species	Local name	South Aceh District								Aceh Singkil District					Total	Red List IUCN	Population trend
			1	2	3	4	5	6	7	8	9	10	11	12	13			
Ambassidae	*Ambassis miops*	*Serideng*	-	-	-	1	5	-	-	-	1	-	5	124	-	136	LC	Stabile
	Ambassis vachellii	*Serideng*	-	-	-	1	-	-	5	-	-	-	-	7	-	13	LC	Unknown
Anabantidae	*Anabas testudineus*	*Kruep*	3	-	-	-	-	-	4	-	-	-	-	-	-	7	LC	Stabile
Anguillidae	*Anguilla bicolor*	*Kiree*	-	-	1	-	1	-	-	-	-	-	-	-	-	2	NT	Unknown
Aplocheilidae	*Aplocheilus panchax*	*Kepala Timah*	-	3	-	-	-	-	-	-	-	-	-	-	-	3	LC	Unknown
Bagridae	*Mystus bimaculatus*	*Suik*	-	-	-	-	-	-	-	-	-	9	-	-	-	9	NT	Decline
Carangidae	*Caranx sexfasciatus*	*Rambeu*	-	-	-	7	1	-	-	-	-	-	-	3	-	11	LC	Decline
Channidae	*Channa lucius*	*Bujok*	-	-	-	-	-	-	-	-	-	5	-	-	-	15	LC	Stabile
	Channa striata	*Gabus*	1	-	1	-	16	-	5	-	1	3	5	-	-	32	LC	Stabile
Cichlidae	*Oreochromis niloticus*	*Nila*	-	-	1	-	-	-	-	-	-	-	-	-	-	1	LC	Unknown
Clariidae	*Clarias batrachus*	*Limbek*	-	2	-	1	6	7	-	-	-	7	-	-	-	43	LC	Stabile
Cyprinidae	*Cyclocheilichthys apogon*	*Ikan Phet*	-	-	-	-	-	-	-	-	10	-	4	-	-	14	LC	Unknown
	Cyclocheilichthys armatus	*Mirah Mata*	-	3	20	-	-	-	-	-	2	-	3	-	-	28	LC	Unknown
	Osteochilus kappenii	*Serukan*	-	1	-	-	-	-	-	-	-	7	-	-	-	8	LC	Stabile
	Osteochilus vittatus	*Serukan*	-	2	1	-	-	-	-	-	60	5	-	-	-	68	LC	Stabile
	Puntius brevis	*Groe*	-	5	13	-	1	-	-	-	-	1	-	-	-	20	LC	Unknown
	Rasbora api	*Bileh Krueng*	-	-	7	149	-	-	-	-	-	-	-	-	-	156	LC	Stabile
	Rasbora sumatrana	*Kedawah*	-	3	4	-	-	-	-	-	-	-	-	-	-	7	DD	Unknown
Eleotridae	*Ophiocara porocephala*	*Cong Itam*	-	-	-	-	-	-	-	-	-	-	-	3	-	3	LC	Stabile
Gerreidae	*Gerres erythrourus*	*Kapas-kapas*	-	-	-	-	-	-	-	-	-	-	-	-	1	1	LC	Unknown
	Gerres longirostris	*Kapas-kapas*	-	-	-	1	-	-	-	1	-	-	-	1	3	6	LC	Unknown
Gobiidae	*Glossogobius giuris*	*Cong*	-	-	-	-	-	-	-	-	-	-	-	4	2	6	LC	Unknown
	Taenioides cirratus	*Ikan Uwak*	-	-	-	-	-	-	-	-	-	-	-	-	1	1	DD	Unknown
Haemulidae	*Pomadasys argenteus*	*Toktok puteh*	-	-	-	13	-	-	-	-	-	-	-	-	-	13	LC	Stabile
	Pomadasys kaakan	*Toktok belang*	-	-	-	14	-	-	-	-	-	-	-	-	-	14	LC	Unknown
Leiognathidae	*Leiognathus equulus*	*Cirik Tanah*	-	-	-	5	-	-	-	4	-	-	-	-	-	9	LC	Unknown
Lutjanidae	*Lutjanus argentimaculatus*	*Bateng*	-	-	-	-	-	-	-	-	-	-	-	2	1	3	LC	Unknown
	Lutjanus fulviflamma	*Ikan Tanda*	-	-	-	-	-	-	-	-	-	-	-	-	2	2	LC	Unknown
Megalopidae	*Megalops cyprinoides*	*Ikan Bulan*	-	-	-	-	1	-	-	-	-	-	-	-	-	1	DD	Unknown
Mugilidae	*Mugil cephalus*	*Belanek*	-	-	-	5	1	-	-	-	-	-	1	-	-	7	LC	Stabile
	Valamugil cunnecius	*Kadra*	-	-	-	1	1	-	16	-	-	-	-	-	-	18	NE	Unknown
Mullidae	*Upeneus sulphureus*	*Ikan Kambing*	-	-	-	5	-	-	-	-	-	-	-	-	-	5	LC	Stabile
Osphronemidae	*Trichopodus trichopterus*	*Sepat Rawa*	131	15	2	1	-	8	61	-	11	-	-	-	-	229	LC	Unknown
Oxudercidae	*Periophthalmus argentilineatus*	*Cicak Bakoi*	-	-	-	-	-	-	1	-	-	-	-	2	-	3	LC	Unknown
Siluridae	*Kryptopterus minor*	*Leupek*	-	1	1	-	-	-	-	-	-	-	-	-	-	2	NT	Decline
Soleidae	*Solea ovata*	*Ikan Sebelah*	-	-	-	-	-	-	-	1	-	-	-	-	-	1	LC	Unknown
Terapontidae	*Terapon theraps*	*Kirong*	-	-	-	7	-	-	-	-	-	-	-	-	-	7	LC	Unknown
Toxotidae	*Toxotes chatareus*	*Sumpit*	-	-	-	-	-	-	-	-	-	-	-	2	-	2	LC	Stabile
Zenarchopteridae	*Zenarchopterus dispar*	*Ikan Murong*	-	-	-	3	-	-	-	-	-	-	-	25	-	28	LC	Unknown
Total individual			135	35	51	214	33	15	92	6	85	67	18	173	10	934		
Total species			3	9	10	15	9	2	6	3	6	7	5	10	6			

Notes: South Aceh District I = Seunabok Jaya AFD 5; II = Seunabok Pusaka AFD 4; III = Seunabok Pusaka AFD 1; IV = Alur Seunuebuk, V = Ie Meudama,VI = Teupin Tinggi; VII = Kota Padang; VIII = Krueng Impadang; IX = Desa Raket; and X = Buloh Seuma), Aceh Singkil District (XI= Suka Jaya, XII= Kuala Baru Laut, and XIII= Kilangan Village Port), Near Threatened (NT), Least Concern (LC), Data Deficient (DD), dan Not Evaluated (NE)

Table 3. Fish community structure in the Singkil peat swamp, Aceh Province, Indonesia

District	Sampling location/ station	Total ind.	Total species	Shannon Winer Diversity index (H)	Domance index (D)	Species richness (d)
South Aceh	Seunabok Jaya AFD 5 (St. I)	135	3	0.15	0.94	0.41
	Seunabok Pusaka AFD 4 (St. II)	35	9	1.80	0.23	2.25
	Seunabok Pusaka AFD 1 (St.III)	51	10	1.70	0.25	2.29
	Alur Seunuebuk (St.IV)	214	15	1.30	0.50	2.61
	Ie Meudama (St.V)	33	9	1.58	0.30	2.29
	Teupin Tinggi (St.VI)	15	2	0.69	0.50	0.37
	Kota Padang (St.VII)	92	6	1.08	0.48	1.11
	Krueng Impadang (St.VIII)	6	3	0.87	0.50	1.12
	Desa Raket (St.IX)	85	6	0.96	0.53	1.13
	Buloh Seuma (St. (St.X)	67	7	1.60	0.25	1.43
Aceh Singkil	Suka Jaya (St.XI)	18	5	1.51	0.23	1.38
	Kuala Baru Laut (St.XII)	173	10	1.06	0.54	1.75
	Kilangan Village Port (St.XIII)	10	6	1.70	0.20	2.17
Min				0.15	0.20	0.37
Max				1.80	0.94	2.61
Average				1.23	0.42	1.56

Table 4. Total fish biomass according to sampling location in the Singkil peat swamp, Aceh Province, Indonesia

District	Sub district	Sampling location (station)	Biomassa (kg/ha)
South Aceh	East Trumon	Seunabok Jaya AFD 5 (St.1)	206.79
		Seunabok Pusaka AFD 4 (St.2)	423.31
		Seunabok Pusaka AFD 1 (St.3)	536.10
	Trumon	Alur Seunuebuk (St.4)	244.01
		Ie Meudama (St.5)	665.22
		Teupin Tinggi (St.6)	209.77
		Kota Padang (St.7)	70.31
		Krueng Impadang (St.8)	68.71
		Desa Raket (St.9)	435.15
		Buloh Seuma (St. (St.10)	456.52
Aceh Singkil	Kuala Baru	Suka Jaya (St.11)	142.61
		Kuala Baru Laut (St.12)	254.55
	Singkil	Kilangan Village Port (St.13)	40.64
Minimum			40.64
Maximum			665.22
Average			288.75

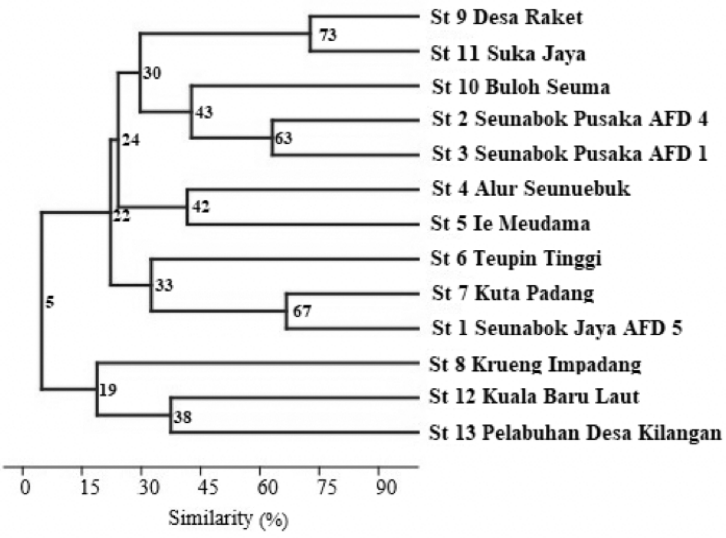

Figure 10. The similarity of the fish community structure of the Singkil peat swamp, Aceh Province, Indonesia

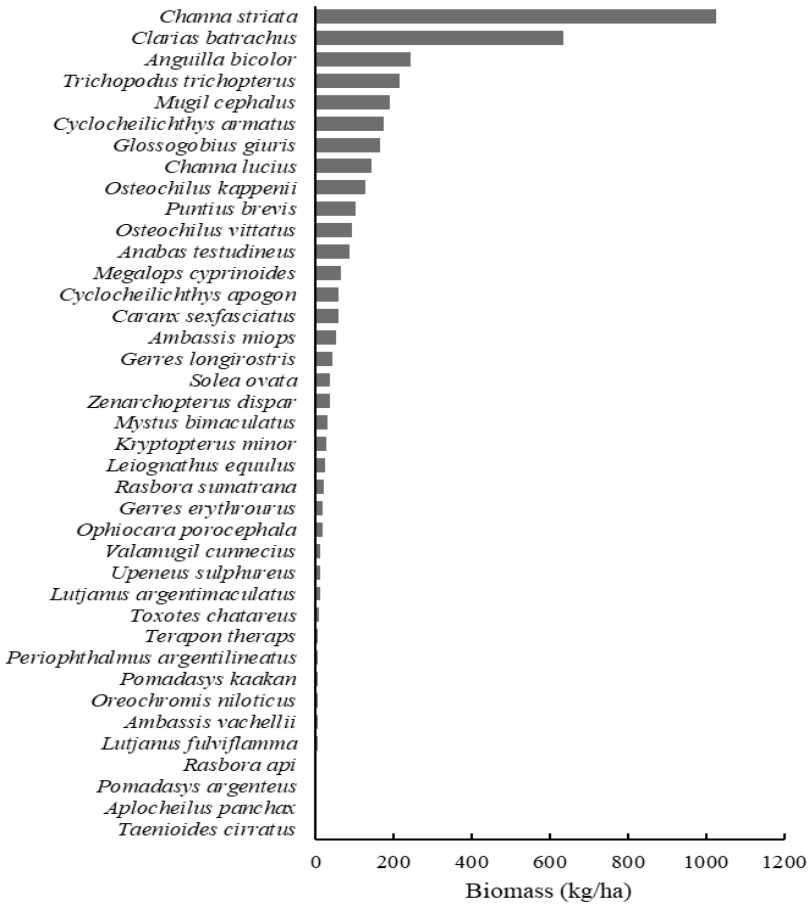

Figure 11. Fish biomass according to species in the Singkil peat swamp, Aceh Province, Indonesia

Fish biomass

Fish biomass in the Singkil peat swamp ranged from 40.64 kg/ha to 665.22 kg/ha, with an average value of 288.75 kg/ha. The highest value of 665.22 kg/ha was recorded at St. V (Ie Meudama), while the lowest of 40.64 kg/ha was obtained at St. 13 (Pelabuhan Desa Kilangan Village). Based on species, the fish with the highest biomass were *C. striata* and *C. batrachus*, with values of 1027.09 kg/ha and 634.96 kg/ha, respectively (Figure 11; Table 4).

Main water quality parameters

The results showed that the water temperature, dissolved oxygen, water pH, and salinity ranged from 28.2 to 33.5°C, 3.9 to 6.8 mg/L, 4.6 to 8.7, and 0 to 22 ppt, respectively (Table 1). Furthermore, the condition of these parameters was considered suitable for fish life.

Discussion

This study showed that Cyprinidae was the most dominant family in the Singkil peat swamp. Cyprinidae, commonly referred to as carp or minnow, was a group of true freshwater fish (Muchlisin et al. 2015a; Su and Su 2018; Lin et al. 2019). At present, approximately 1,270 species of cyprinids are reported to be living in freshwater around the world (Ng et al. 2018; Ramoejane et al. 2020; Froese and Pauly 2021; Kambikambi et al. 2021). Apart from the Singkil peat swamp, this group of fish also dominated several rivers or ecosystems in Indonesia, including the Tripa Peat Swamp (Muchlisin et al. 2015a), the Krueng Geumpang and Krueng Sabee Rivers (Nasir et al. 2018; Timorya et al. 2018; Nasir et al. 2021), Krueng Aceh River, Aceh Province (Dekar et al. 2018), and Batangtoru River, North Sumatra (Desrita et al. 2020). Furthermore, the majority of the fish species had the potential to be cultured for both consumption and ornamental purposes. Muchlisin et al. (2015a) identified several potential cultivated species in Aceh waters, including *Anabas testudineus* (Bloch, 1792) (climbing perch), *Channa striata* (snakehead), *C. lucius* (javanese snakehead), and *Clarias batrachus* (walking catfish), and these species were also detected in the Singkil peat swamp.

The species with the largest number of individuals was *T. tricopterus* and *C. striata.* These two samples were found in swamps, canals, and wetlands in the Singkil peat swamp area, and their frequency of occurrence was classified as frequently found. Therefore, they had the highest adaptability to the conditions of the Singkil peat swamp. This could be attributed to the presence of additional respiratory organs in *T. trichopterus* and *C. striata*, namely labyrinth and diverticula, respectively (Karlina and Jaâ 2018; Perdana et al. 2021; Nur et al.

2023), thereby enhancing their survival in rough waters with low oxygen. Apart from the adaptability, the distribution and occurrence of a fish species were also influenced by the environmental conditions, such as the availability of shelters, currents, food availability, and water topography (Wang et al. 2020; Zhou et al. 2020). Furthermore, fish distribution was influenced by physical and chemical factors in the water, such as pH, temperature, current speed, dissolved oxygen, and depth (Barus 2021; Brysiewicz et al. 2022).

The species richness and diversity in the Singkil peat swamp were classified as moderate, and the fish diversity values obtained were lower compared to the Tripa Peat Swamp (Muchlisin et al. 2015a). The low diversity in the Singkil peat swamp was thought to be related to habitat perturbation by land conversion to oil palm plantations, leading to the dryness of several river channels and swamps. However, the total species of fish in the Singkil peat swamp was higher than peat swamp in the Yak Yah peat swamp, Terengganu, West Coast of Peninsular Malaysia i.e., 14 species out of 95 individuals, and peat swamp in the North Selangor i.e., 9 species out of 43 individuals (Hussin-Jasmin et al. 2021; Saadu et al. 2021). The biomass analysis showed that the average value in the Singkil peat swamp was 288.75 kg/ha, where the fish species with the highest value was *C. striata* (1027.09 kg/ha), followed by *C. batrachus* (634.96 kg/ha). Therefore, the average biomass obtained was lower compared to that of Lake Sembuluh and Papudak, Central Kalimantan (461.8 kg/ha) (Kartamihardja et al. 2017). The results also showed that the value was slightly higher compared to Ujung Pancu, Aceh Besar (Fazillah et al. 2020), and Mentawai Islands waters (Suparno et al. 2021), namely 46.27 kg/ha and 205.79 kg/ha, respectively.

According to Brandl et al. (2018), the high abundance of fish species in an ecosystem was an indicator of the good quality of the aquatic ecosystem, which provided habitats for different purposes, including spawning, foraging, and nursery grounds. According to McClanahan and Jadot (2017), there was a strong positive correlation between diversity and total biomass. In this study, the location with the highest diversity was Alur Seuneubok (St. 4), while the largest biomass was recorded in the Ie Meudama location (St. 5). This was because the species found in the Seuneubok Alur (St. 4) were small fish, such as the genus *Rasbora*, *Trichopodus*, and *Puntius*, etc., and genetically, these fish are small in size. Hence, apart from being influenced by the number of species, fish biomass was also affected by the size (weight) of the samples.

This study showed that 1 alien fish species was recorded, namely tilapia *O. niloticus*. This fish was found in a single location, namely at Seunebok Pusaka AFD 1 (St. 3). Furthermore, tilapia was an invasive species that was widely distributed in Aceh (Muchlisin 2012) and was found in the Tripa Peat Swamp (Muchlisin et al. 2015a). The tilapia has been introduced to more than 85 countries; of these, 15 countries report that this fish has become invasive (Cassemiro et al. 2018; Stauffer Jr et al. 2022). According to previous studies, it had become a dominant species in Lake Laut Tawar and replaced depik *R. tawarensis*, the endemic fish, to this lake (Batubara et al. 2019). *O. niloticus* was first introduced to Indonesia around 1969 and to Aceh during the 1990s (Nasir et al. 2018). Muchlisin (2013) stated that the policy of introducing alien fish was an unwise policy for the country, specifically in Aceh, due to the presence of a diverse range of high-value species. The presence of invasive fish could potentially threaten biodiversity in a body of water (Reid et al. 2019; Hughes et al. 2020; Nasution et al. 2022). Therefore, a campaign was needed to raise public awareness about the negative impacts of the introduced fish, including predation on indigenous species (Magalhaes et al. 2020; Moi et al. 2021), competition for food, habitat, and mate (Gomes-Silva et al. 2020; Calizza et al. 2021; Zhang et al. 2022), and crossbreeding with native fish. These factors led to a reduction in the genetic diversity and distinctiveness of native fish, as well as the transmission of disease (Zhang et al. 2022). At present, there have been no strategic efforts to control the spread of potentially invasive fish in Aceh. This indicated that the active role of the local government in developing regulations and strict enforcement in their implementation were crucially needed to control the spread of invasive species.

In conclusion, a total of 39 species of fish, belonging to 26 families and 31 genera, were successfully documented during this study. Alue Seuneubok had the highest number of species (15 species), and Cyprinidae was the most dominant family in the Singkil peat swamp. Furthermore, the fish diversity index in Singkil peat swamp was classified as moderate, and the dominance index was low. *C. striata* and *T. trichopterus* were reported to have the highest frequency of occurrence. The average fish biomass was 288.75 kg/ha, where the highest biomass was recorded at the Ie Meudama location (St 5). The results showed that *C. striata* and *C. batrachus* had the highest biomass compared to other species. Among the 39 fish species, three were in the near threatened category, including *A. bicolor*, *M. bimaculatus*, and *K. minor*, and 1 invasive species was found, namely *O. niloticus*.

ACKNOWLEDGEMENTS

This study was funded by Universitas Syiah Kuala through the Program *Riset Unggulan Universitas Syiah Kuala Percepatan Doktor* (PRUU-PD) scheme for the corresponding author (contract number: 536/UN11.2.1/PT.01.03/PNBP/2023). The authors are also grateful to the Rector of Universitas Kuala Syiah University for supporting this study.

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