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RISK ASSESSMENT OF INTRODUCED FISH SPECIES AS A BIODIVERSITY MITIGATION EFFORT IN LAKE TOBA, NORTH SUMATRA, INDONESIA

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Risk Assessment of Introduced Fish Species as A Biodiversity Mitigation Effort in Lake Toba, North Sumatra, Indonesia. Batubara, A. S., Muliari, M., Manurung, B., Sipahutar, H., Akmal, Y., Irfannur,I., Maulizar, S., Nur, F. M., Ritonga, Y. E., Lubis, K. — Lake Toba's environment and ichthyofauna are degrading due to human activities and the introduction of invasive fish species. Studies are needed

to identify species, distribution patterns, densities and risks of introduced fish species, and these studies must be conducted using scientific and measurable approaches. Research was conducted in Lake Toba, North Sumatra, Indonesia, from June to August 2024, at ten research locations. The research employed an exploratory method, measuring parameters such as population density, the Shannon-Wiener diversity index (H'), the evenness index (E), and the Simpson dominance index (C). Furthermore, this research measures the risk of invasiveness using the Fish Invasiveness Screening Test (FIST). Nine introduced fish species have become established in Lake Toba, including *Amphilophus labiatus* (Günther, 1864), *Aplocheilus panchax* (Hamilton, 1822), *Cyprinus carpio* Linnaeus, 1758, *Mystacoleucus padangensis* (Bleeker, 1852), *Oreochromis mossambicus* (Peters, 1852), *O. niloticus* (Linnaeus, 1758), *Poecilia reticulata* Peters, 1859, *Puntigrus tetrazona* (Bleeker, 1855), and *Xiphophorus helleri* Heckel, 1848. Population density values show that *P. reticulata* has the highest average value reaching 6.02 ind/m^2, followed by *A. labiatus* 2.21 ind/m^2, M. *padangensis* 0.21 ind/m^2, *O. niloticus* 0.14 ind/m^2, *P. tetrazona* 0.08 ind/m^2, *X. helleri* 0.03 ind/m^2, and 0.01 ind/m^2 in *A. panchax*, *C. carpio*, and *O. mossambicus*, respectively. Diversity index analysis show low diversity (mean of 0.7), evenness index shows unstable community (mean of 0.46), and Simpson dominance index shows the presence of a dominant species (mean of 0.63). The results of the FIST analysis show that five introduced fish species are in the high risk category, three species have a moderate risk and one species has a low risk. *O. niloticus*, *A. labiatus*, *C. carpio*, *O. mossambicus*, and *P. reticulata* have a high risk for ichthyofauna diversity and in fact cause low diversity in Lake Toba.

Key words: Caldera, geopark, invasiveness, diversity, distribution.

Introduction

Lake Toba was formed by a volcanic eruption that created a caldera, a volcanic crater that can hold water. Lake Toba is the largest lake in Indonesia and the largest tectonic lake in the world with a length of 87 km, a width of 27 km and a depth of 500 m (Stankiewicz et al., 2010; Tatsuno et al., 2021; Fukushima et al., 2023). The United Nations Educational, Scientific and Cultural Organization (UNESCO) agreed to designate the Caldera Toba as a UNESCO Global Geopark at the 209th Session of the UNESCO Executive Board in Paris on 7 July 2020 (Ministry of Foreign Affairs of the Republic of Indonesia, 2020). Through this determination, Indonesia can develop the Caldera Toba Geopark through the Global Geoparks Network and Asia Pacific Geoparks Network, especially in relation to empowering local communities. The designation of the Caldera Toba as a UNESCO Global Geopark provides an opportunity and also a responsibility for Indonesia to develop the economy and sustainable development, especially preserving culture and biodiversity.

Previous research reports reveal that Lake Toba has experienced environmental degradation and a decline in ichthyofauna diversity due to human activities and the introduction of invasive fish species (Saragih & Sunito, 2001; Irwandi et al., 2021). Introduced fish are species of fish that enter a new habitat for consumption or ornamental purposes (Rahel & Taniguchi, 2019). The introduction of non-native fish to Lake Toba is predicted to put pressure on the native fish population, meaning that native fish have become increasingly difficult to find in recent years (Moedjodo et al., 2003). The decline in native fish populations has a significant socio-economic impact on fishermen working in Lake Toba, as evidenced by a decrease in catches (Kartamihardja et al., 2015). Therefore, immediate conservation efforts are necessary for the biodiversity of Lake Toba, particularly its ichthyofauna, to ensure its long-term sustainability.

Previous research revealed that there were 8 species of introduced fish in Lake Toba, including the *Amphilophus labiatus* (Günther, 1864), *Aplocheilus panchax* (Hamilton, 1822), *Cyprinus carpio* Linnaeus, 1758, *Mystacoleucus marginatus* (Valenciennes,

1842), *M. padangensis* (Bleeker, 1852), *Oreochromis mossambicus* (Peters, 1852), *O. niloticus* (Linnaeus, 1758), and *Parambassis siamensis* (Fowler, 1937) (Kartamihardja et al., 2015; Kaban & Wibowo, 2018; Lubis & Ibrohim, 2019; Qomaria, 2023). Introduced fish species into Lake Toba had a significant impact on the decline in native fish populations, such as the groups of fish in the genus *Neolissocheilus*, *Osteochilus*, *Puntius*, *Rasbora*, and *Tor* (Roesma et al., 2016). The reason for this is that several species of introduced fish are invasive, thereby suppressing native fish populations.

Various authorities have carried out several biodiversity mitigation efforts in Lake Toba, but the significant impact has not yet been felt. The population of introduced fish species has not decreased; in fact, it is increasing (Suara Manado, 2022). Significant efforts will be needed in the near future. The presence of introduced fish in Lake Toba is a very worrying issue. Conservation efforts for native fish must be carried out by controlling the introduced species that have already entered the lake. Therefore, it is important to carry out scientific and measurable studies to identify species, distribution patterns, densities and risks of introduced fish, as this is the initial information needed. The results of this study will inform future strategies for dealing with invasive introduced fish, helping to preserve biodiversity in the Toba Caldera as a UNESCO Global Geopark.

Material and Method

Site and time

Research was conducted in Lake Toba, North Sumatra, Indonesia from June to August 2024 (Fig. 1). Fish samples were collected from 10 stations including (1) Ajibata, (2) Porcea, (3) Balige, (4) Muara, (5) Bakti Raja, (6) Pangururan, (7) Onan Runggu, (8) Tomok, (9) Silalahi, and (10) Tongging (Fig. 1). The samples that had been collected were then taken to the Biology Laboratory, Universitas Negeri Medan for further analysis.

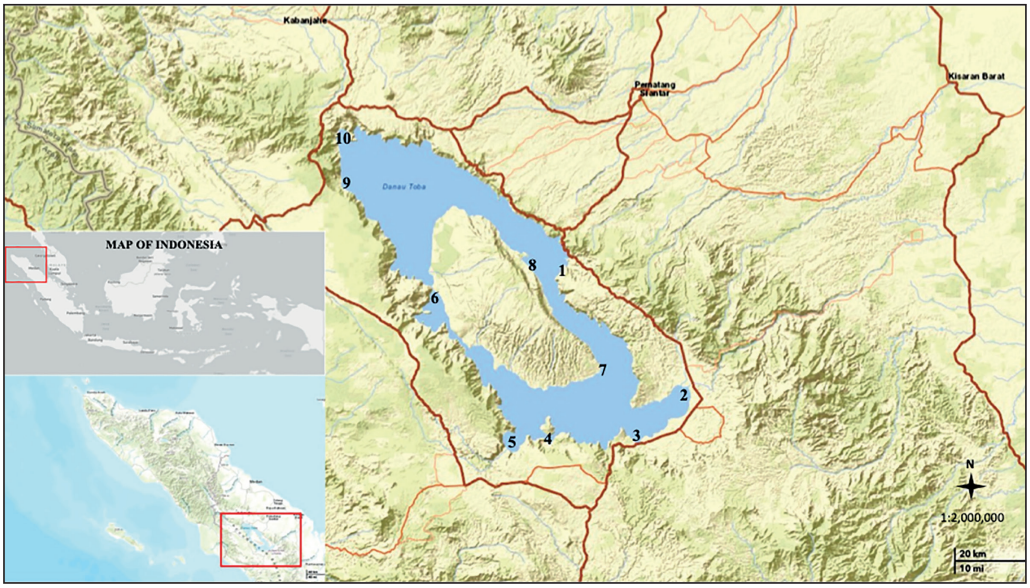

Fig. 1. Map of research locations in Lake Toba including (1) Ajibata, (2) Porcea, (3) Balige, (4) Muara, (5) Bakti Raja, (6) Pangururan, (7) Onan Runggu, (8) Tomok, (9) Silalahi, and (10) Tongging

Research procedures

This research uses an exploratory method. Fishing is done using gill nets, nets, fishing rods, traps and scoops. The collected fish samples were separated by species and the quantity recorded. Each fish specimen was photographed with its head facing to the left (Sukmono et al., 2013). For further identification, each species of fish is then placed in a plastic sample containing 4% formalin and labeled (Hidayat et al., 2023). Identification of introduced fish is carried out based on the morphological characters of the fish (Kottelat, 2013).

Data analysis

In determining the distribution of introduced fish species, it is analyzed using the frequency index formula. The frequency index is the percentage of a introduced fish species found at the research location. The frequency index is calculated using an equation based on Muchlisin (2012), namely: $Fi = L_i/L_t \times 100$, where Fi is the frequency index, L_i is the frequency of the ith species at the sampling location found, L_t is the total sampling location. Diversity indices between locations measured include the Shannon-Wienner diversity index (H'), Evenness index (E) and Simpson dominance index (C) (Rahim et al., 2023).

Determination of zones and natural distribution of introduced fish was carried out based on reported literature and FishBase (https://www.fishbase.org/search.php). The determination of the conservation status of introduced fish refers to data from The IUCN Red List of Threatened Species (https://www.iucnredlist.org/). Furthermore, to determine the time of introduction of introduced fish into Indonesia, authors referred to various data including the Database of Introduced Aquatic Species (DIAS) (https://www.fao.org/fishery/dias/en) and journal. The risk assessment of introduced fish was carried out using the Fish Invasiveness Screening Test (FIST) (Saba et al., 2020). The authors also refers to the Regulation of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia (PERMEN-KP) Number 41 of 2014 (https://jdih.kkp.go.id/Homedev/DetailPeraturan/509) and Number 19 of 2020 (https://jdih.kkp.go.id/Homedev/DetailPeraturan/852) concerning introduced fish species that are prohibited from trading in Indonesia.

Results

The identification results show that nine introduced fish species have become established in Lake Toba, including *Amphilophus labiatus*, *Aplocheilus panchax*, *Cyprinus carpio*, *Mystacoleucus padangensis*, *Oreochromis mossambicus*, *O. niloticus*, *Poecilia reticulata*, *Puntigrus tetrazona*, and *Xiphophorus helleri* (Fig. 2), which are divided into the families Cichlidae and Cyprinidae three species each, Poeciliidae two species, and Aplocheilidae one species (Table 1). Based on the frequency index value, it shows that *A. labiatus* and *O. niloticus* reached 100% were found in all sampling locations, followed by *P. tetrazona* with a value of 70%, *M. padangensis* and *P. reticulata* with 60% each, *A. panchax* and *C. carpio* 30% each, *O. mossambicus* and *X. helleri* 10% each (Table 2).

Population density values show that *P. reticulata* has the highest average value reaching 6.02 ind/m^2, followed by *A. labiatus* 2.21 ind/m^2, *M. padangensis* 0.21 ind/m^2,

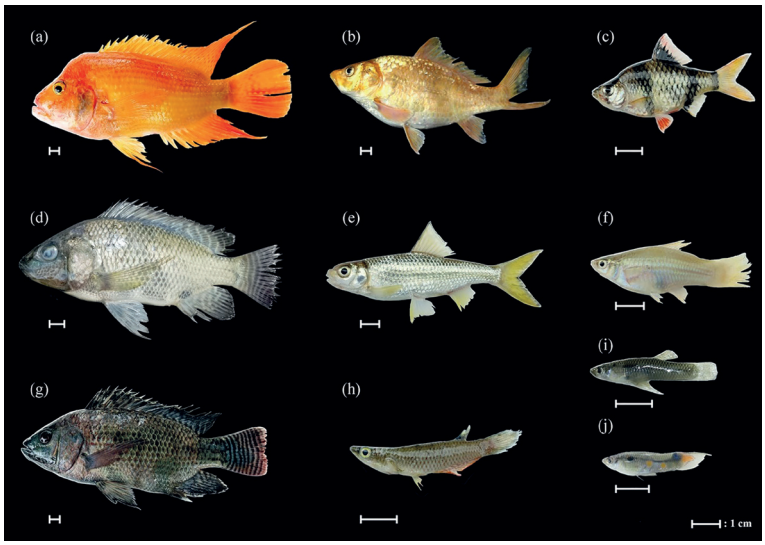

Fig. 2. Introduced fish species were established in Lake Toba, North Sumatra, Indonesia, where (a) *Amphilophus labiatus*, (b) *Cyprinus carpio*, (C) *Puntigrus tetrazona*, (d) *Oreochromis niloticus*, (e) *Mystacoleucus padangensis*, (f) *Xiphophorus helleri*, (g) *Oreochromis mossambicus*, (h) *Aplocheilus panchax*, and *Poecilia reticulata* (i = female, j = male)

Table 1. **Order, species, common name, local name, and distribution of introduced fish species in the Lake Toba, North Sumatra, Indonesia**

Ordo	Species	Common Name	Local Name	Distribution
		Cichliformes		
Cichlidae	*Amphilophus labiatus* Günther, 1864	Red Devil	Red Devil	Central America: Nicaragua and Managua
	Oreochromis mossambicus Peters, 1852	Mozambique Tilapia	Mujahir	Africa: Widespread in several regions of Africa
	Oreochromis niloticus Linnaeus, 1758	Nile Tilapia	Nila	Africa: Widespread in several regions of Africa
		Cypriniformes		
Cyprinidae	*Cyprinus carpio* Linnaeus, 1758	Common Carp	Mas, Koi	Eurasia: Caspian and Aral Basin
	Mystacoleucus padangensis Bleeker, 1852*	Bilih	Pora -Pora	Indonesia: Lake Singkarak and Lake Maninjau, West Sumatra
	Puntigrus tetrazona Bleeker, 1855*	Sumatra Barb	Tetra Sumatra	Indonesia: Batanghari River, Jambi
		Cyprinodontiformes		
Aplocheilidae	*Aplocheilus panchax* Peters, 1859*	Blue Panchax	Kepala Timah	Asia: Pakistan, India, Bangladesh, Myanmar, and the Indo-Malaysian archipelago
Poeciliidae	*Poecilia reticulata* Peters, 1859	Gupy	Seribu	South America: Venezuela, Barbados, Trinidad, Brazil, and Guyana
	Xiphophorus helleri Heckel, 1848	Green Swordtail	Platy	North-South America: Mexico and Honduras

* Indicates the species is native to Indonesia but Lake Toba is not its distribution zone

O. niloticus 0.14 ind/m^2, *P. tetrazona* 0.08 ind/m^2, *X. helleri* 0.03 ind/m^2, and 0.01 ind/m^2 in *A. panchax*, *C. carpio*, and *O. mossambicus*, respectively (Table 2 and Fig. 3). Based on relative density values, *A. labiatus* had higher values in seven locations compared to other species, including Porcea (85.51%), Balige (49.22%), Bakti Raja (75.36%), Onan Runggu (83.39%), Tomok (75.99%), Silalahi (62.23%), and Tongging (98.98%), while the other three locations were dominated by *P. reticulata* with details of Ajibata

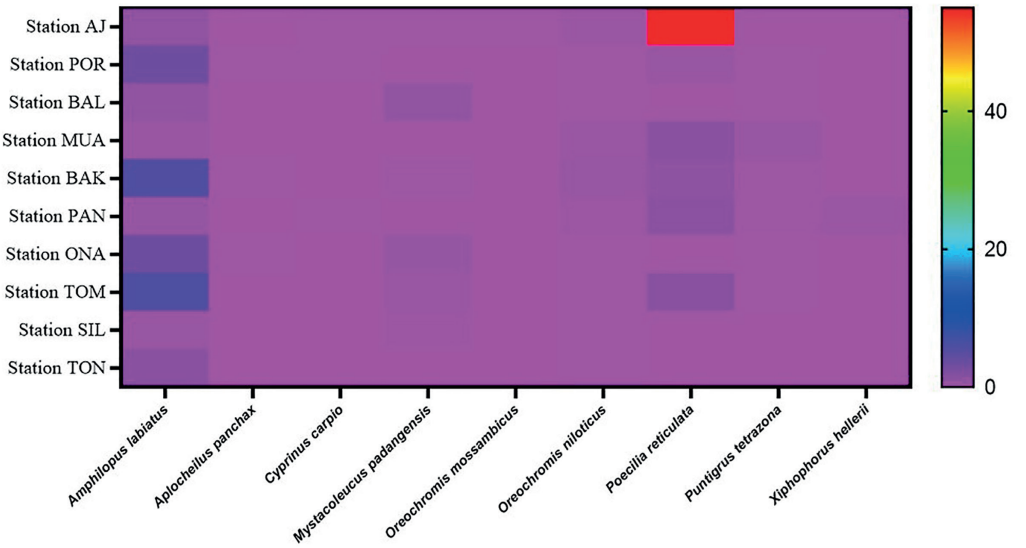

Fig. 3. Graph of density population (ind/m^2) of introduced fish species in Lake Toba includes Ajibata (AJ), Porcea (POR), Balige (BAL), Muara (MUA), Bakti Raja (BAK), Pangururan (PAN), Onan Runggu (ONA), Tomok (TOM), Silalahi (SIL), and Tongging (TON)

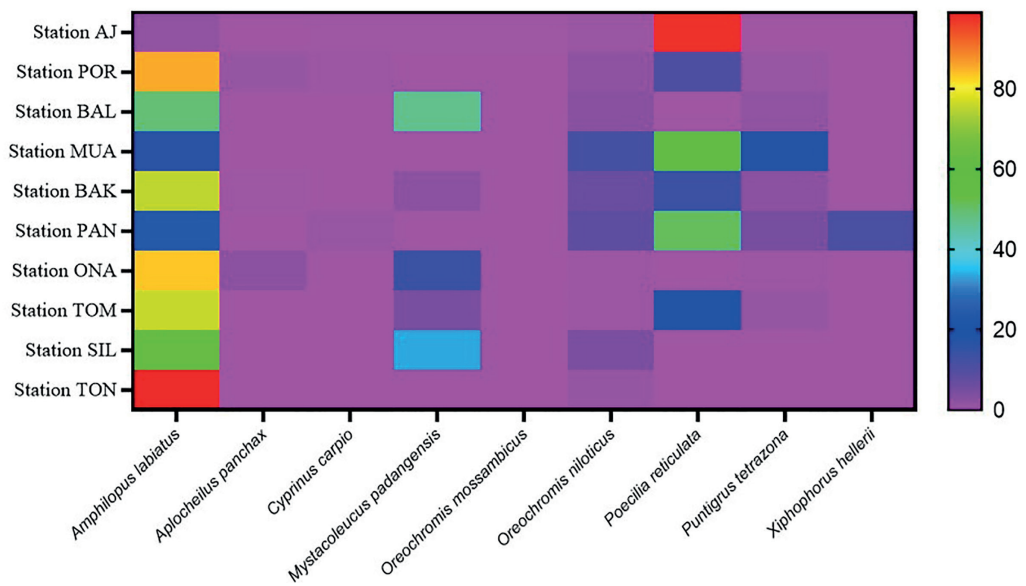

Fig. 4. Graph of relative density (%) of introduced fish species in Lake Toba including Ajibata (AJ), Porcea (POR), Balige (BAL), Muara (MUA), Bakti Raja (BAK), Pangururan (PAN), Onan Runggu (ONA), Tomok (TOM), Silalahi (SIL), and Tongging (TON)

Table 2. **Population density (ind/m²) and frequency index (Fi) of introduced fish species in Lake Toba based on research location**

Species	Population density (ind/m²)										Mean	Fi (%)
	AJ	POR	BAL	MUA	BAK	PAN	ONA	TOM	SIL	TON		
Amphilophus labiatus Günther, 1864	0.89	3.23	0.84	0.36	5.59	0.56	3.28	5.65	0.39	1.29	2.21	100
Aplocheilus panchax Hamilton, 1822	–	0.04	–	–	0.01	–	0.08	–	–	–	0.01	30
Cyprinus carpio Linnaeus, 1758	0.03	0.01	–	–	–	0.02	–	–	–	–	0.01	30
Mystacoleucus padangensis Bleeker, 1852	0.04	–	0.8	–	0.16	-	0.55	0.33	0.21	–	0.21	60
Oreochromis mossambicus Peters, 1852	0.08	–	–	–	–	–	–	–	–	–	0.01	10
Oreochromis niloticus Linnaeus, 1758	0.28	0.07	0.04	0.27	0.48	0.19	0.01	0.03	0.03	0.01	0.14	100
Poecilia reticulata Peters, 1859	55	0.4	–	1.21	1.01	1.19	–	1.35	–	–	6.02	60
Puntigrus tetrazona Bleeker, 1855	–	0.03	0.03	0.39	0.16	0.11	0.01	0.08	–	–	0.08	70
Xiphophorus hellerii Heckel, 1848	–	–	–	–	–	0.26	–	–	–	–	0.03	10

Information: Ajibata (AJ), Porcea (POR), Balige (BAL), Muara (MUA), Bakti Raja (BAK), Pangururan (PAN), Onan Runggu (ONA), Tomok (TOM), Silalahi (SIL), and Tongging (TON).

Table 3. **Relative density (%) of introduced fish species in Lake Toba based on research location**

Species	Relative density (%)										Mean
	AJ	POR	BAL	MUA	BAK	PAN	ONA	TOM	SIL	TON	
Amphilophus labiatus Günther, 1864	1.59	85.51	49.22	16.17	75.36	24.03	83.39	75.99	62.23	98.98	57.2
Aplocheilus panchax Hamilton, 1822	–	1.06	–	–	0.18	-	2.03	–	–	–	0.33
Cyprinus carpio Linnaeus, 1758	0.05	0.35	–	–	-	0.86	–	–	–	–	0.13
Mystacoleucus padangensis Bleeker, 1852	0.07	–	46.88	–	2.16	-	13.9	4.48	33.51	–	10.1
Oreochromis mossambicus Peters, 1852	0.14	–	–	–	–	–	–	–	–	–	0.01
Oreochromis niloticus Linnaeus, 1758	0.5	1.77	2.34	11.98	6.47	8.15	0.34	0.36	4.26	1.02	3.72
Poecilia reticulata Peters, 1859	97.66	10.6	–	54.49	13.67	51.07	–	18.1	–	–	24.6
Puntigrus tetrazona Bleeker, 1855	–	0.71	1.56	17.37	2.16	4.72	0.34	1.08	–	–	2.79
Xiphophorus hellerii Heckel, 1848	–	–	–	–	–	11.16	–	–	–	–	1.12

Information: Ajibata (AJ), Porcea (POR), Balige (BAL), Muara (MUA), Bakti Raja (BAK), Pangururan (PAN), Onan Runggu (ONA), Tomok (TOM), Silalahi (SIL), and Tongging (TON).

Table 4. **Results of the Shannon-Wiener diversity index (H'), evenness (E), and dominance (C) of fish species in Lake Toba based on research location**

Ecological Parameters	Sampling locations										Mean
	AJ	POR	BAL	MUA	BAK	PAN	ONA	TOM	SIL	TON	
Shannon-Wiener (H')	0.13	0.55	0.86	1.18	0.84	1.32	0.52	0.73	0.79	0.07	0.7
Evenness (E)	0.07	0.3	0.62	0.85	0.47	0.74	0.32	0.45	0.72	0.08	0.46
Dominance (C)	0.95	0.74	0.46	0.37	0.59	0.34	0.71	0.61	0.5	0.98	0.63

Information: Ajibata (AJ), Porcea (POR), Balige (BAL), Muara (MUA), Bakti Raja (BAK), Pangururan (PAN), Onan Runggu (ONA), Tomok (TOM), Silalahi (SIL), and Tongging (TON).

Table 5. Results of analysis of the Fish Invasiveness Screening Test (FIST) on 9 introduced fish species in Toba Lake, North Sumatra, Indonesia

No	Species	Invasiveness screening criteria								% FD	Invasion Risk
		1	2	3	4	5	6	7	8		
1	*Oreochromis niloticus* Linnaeus, 1758	+++	+++	+++	+++	+++	+++	+++	++	87.5	High
2	*Amphilophus labiatus* Günther, 1864	+	+++	+++	+++	+++	+++	+++	++	75	High
3	*Cyprinus carpio* Linnaeus, 1758	+++	++	+++	+++	+++	+++	+++	+	75	High
4	*Oreochromis mossambicus* Peters, 1852	+	+	+++	+++	+++	+++	+++	++	62.5	High
5	*Poecilia reticulata* Peters, 1859	+	+++	+++	+++	++	++	+++	+++	62.5	High
6	*Aplocheilus panchax* Hamilton, 1822	+	++	+++	+++	+	++	+++	+++	50	Moderate
7	*Puntigrus tetrazona* Bleeker, 1855	+	+++	+	+++	++	+++	+++	++	50	Moderate
8	*Xiphophorus hellerii* Heckel, 1848	+	+	+++	+++	++	++	+++	+++	50	Moderate
9	*Mystacoleucus padangensis* Bleeker, 1852	+	+++	+	+++	++	++	+	++	25	Low

% FD = Frequency Distribution (%)

97.66%, Muara 54.49%, and Pangururan 51.07% (Table 3 and Fig. 4). Distribution map shows *A. labiatus*, *A. panchax*, *C. carpio*, *M. padangensis*, *O. mossambicus*, *O. niloticus*, *P. reticulata*, *P. tetrazona*, and *X. helleri* have fluctuating density values, with the highest density values marked with red areas and the lowest blue area.

The results of diversity index (H') analysis show values between 0.13–1.32 with a mean of 0.7. The highest value of H' was shown at the Pangururan location reach of 1.32, while the lowest was at Ajibata 0.13. The evenness (E) shows a value between 0.07–0.85 with a mean of 0.46. The Simpson dominance index (C) shows a value between 0.34-0.98 with a mean of 0.63 (Table 4).

The results of the Fish Invasiveness Screening Test (FIST) analysis showed that five introduced fish species were at high risk for the biodiversity of Lake Toba with frequency distribution (FD) values reaching 87.5% for *O. niloticus*, *A. labiatus* 75%, *C. carpio* 75%, *O. mossambicus* 62.5%, and *P. reticulata* 62.5%. There are three intro-

duced fish species that have a moderate risk with FD values reaching 50% each in *A. panchax*, *P. tetrazona*, and *X. helleri*, while only *M. padangensis* has a low risk with an FD value of 25% (Table 5).

Discussion

The H' value shows that eight of the ten research locations have low diversity (< 1), while the other two locations have medium diversity (1 > H' < 3). The eight locations that have low diversity include Ajibata, Porcea, Balige, Bakti Raja, Onan Runggu, Tomok, Silalahi, and Tongging, while the two locations that have mederate diversity are Muara and Pangururan. The C value shows that six research locations indicated the presence of a dominant species (C > 0.5), while the other four locations did not (C < 0.5). The six research locations that showed dominating species included Ajibata, Porcea, Bakti Raja, Onan Runggu, Tomok, and Tongging, while the four locations that did not have dominating species were Balige, Muara Pangururan, and Silalahi. Frequency index analysis showed that *A. labiatus and O. niloticus* were found in all research locations (Fi 100%), but the density value showed that *A. labiatus* (mean 2.21 ind/m^2) was higher than *O. niloticus* (mean 0.14 ind/m^2). Furthermore, based on the average relative density value, it shows that *A. labiatus* is the highest compared to other fish reaching 57.2%.

The FIST values revealed that the risk of invasive from *O. niloticus* (FD 87.5%) was the highest compared to other fish, although the mean density and relative density values were lower compared to *A. labiatus*, *M. padangensis*, and *P. reticulata* (Table 5). These results are validated with GISD data which states that *O. niloticus* is listed among the 1000 invasive species in the world. Based on DIAS data, *O. niloticus* has been introduced to Indonesia since 1969 and has been established in various Indonesian waters including island of Sumatra (Muchlisin, 2012; Apriliawati et al., 2024), Java (Haryono & Wahyudewantoro, 2020; Herawati et al., 2021), Bali (Jayanti et al., 2020; Gustiano et al., 2023), Papua (Ohee et al., 2018; Wibowo et al., 2022), Islands Bangka Belitung (Ramadhanu et al., 2023), Bawean (Hasan & Tamam, 2019), Borneo (Rusmilyansari et al., 2021), Sulawesi (Herjayanto et al., 2019; Serdiati et al., 2021), and Yamdena (Insani et al., 2020).

The FIST value revealed that the risk of invasive from *A. labiatus* and *C. carpio* reached FD 75% (high risk), respectively (Table 5). Based on DIAS data, *A. labiatus* was introduced to Indonesia from 1990, while *C. carpio* took longer (< 1990). *A. labiatus* has been established in various Indonesian waters including island of Sumatra (Suryanti et al., 2017; Qomaria, 2023), Java (Sentosa et al., 2021; Fitriani et al., 2022), Bangka (Jatayu et al., 2023), and Papua (Ohee et al., 2020). Furthermore, *C. carpio* has been established in various Indonesian waters including island of Sumatra (Muchlisin, 2012), Java (Herawati et al., 2021; Sentosa et al., 2021), Bali (Jayanti et al., 2020), Borneo (Rusmilyansari et al., 2021), Sulawesi (Herder et al., 2012; Herjayanto et al., 2019), and Papua (Umar & Sulaiman, 2013). Regulation of the Minister of Maritime Affairs and Fisheries of the Republic of Indonesia (PERMEN-KP) No. 41 of 2014 and No. 19 of 2020 prohibits *A. labiatus* from being traded in Indonesia because it can disrupt existing native fish populations. However, this prohibition does

not apply to *C. carpio*, even though this species is listed among the 100 of the World's Worst Invasive Alien Species based on the GISD data.

O. mossambicus and *P. reticulata* have a FIST value of FD 62.5% (high risk), respectively. Based on DIAS data, *O. mossambicus* was introduced to Indonesia in 1939, while *P. reticulata* was introduced in 1920. *O. mossambicus* has been established in various waters of Indonesia, including island of Sumatra (Muchlisin, 2012), Java (Kartamihardja, 1993; Haryono & Wahyudewantoro, 2020; Herawati et al., 2021; Sentosa et al., 2021; Fitriani et al., 2022), Bali (Gustiano et al., 2023), West Nusa Tenggara (Tjahjo & Purnomo, 1998), Sulawesi (Herder et al., 2012), and Papua (Ohee et al., 2018). Furthermore, *P. reticulata* has been established in various waters of Indonesia, including island of Sumatra (Usna et al., 2016), Java (Rachmatika et al., 2001; Haryono & Wahyudewantoro, 2020), Bali (Gustiano et al., 2023), and Sulawesi (Hadiaty & Wirjoatmodjo, 2002; Herder et al., 2012; Herjayanto et al., 2019). *O. mossambicus* is listed among the 100 Worst Invasive Alien Species in the world, while *P. reticulata* is listed among the 1000 invasive species globally according to GISD data.

There are three species of introduced fish species that have a moderate risk (FD 50%), namely *A. panchax*, *P. tetrazona*, and *X. helleri*. Based on their distribution, *A. panchax* and *P. tetrazona* are considered native fish of Indonesia, although Lake Toba is not their original habitat, while *X. helleri* is a non-native fish species that has been introduced to Indonesia. *X. helleri* has established itself in various waters of Indonesia, including island of Sumatra (Muchlisin, 2012), Java (Haryono & Wahyudewantoro, 2020), Bali (Gustiano et al., 2023), West Nusa Tenggara (Sari et al., 2019), and Sulawesi (Serdiati et al., 2021). *P. tetrazona* is recorded as a native species of Indonesia that has its original habitat in the Muara Bulian Waters, Jambi Province (Apriliawati et al., 2024), Lake Buaya, Bukit Tigapuluh National Park, and Kampar River, Riau Province (Mahyudi et al., 2017; Nakagawa et al., 2021; Nofrizal et al., 2023), as well as the Kelekar River, Komering River, Musi River, and Lake Ranau, South Sumatra Province (Muthmainah et al., 2015; Muthmainnah & Gaffar, 2017; Atminarso et al., 2023; Muslim et al., 2024).

M. padangensis is an endemic species in Lake Singkarak, West Sumatra Province, Indonesia but in 2003, this species was released into Lake Toba with the aim of optimizing its population numbers and conservation (Wibowo et al. 2018). Based on the FIST analysis, *M. padangensis* is categorised as low risk (FD 25%), so its presence in Lake Toba does not damage the long-established ecosystem. In addition, *M. padangensis* is a target catch for fishermen in Lake Toba, so its population remains controlled. However, its population has tended to decline based on the amount of fish caught by fishermen in recent years. This likely occurred due to the booming of the *A. labiatus* population in Lake Toba, leading to intense competition for food sources, breeding grounds, and shelter area. The population of *A. labiatus* is uncontrolled because the market value of this fish is low (only those larger than 20 cm sell well), making it not a primary catch for fishermen. This is because the initial purpose of introducing *A. labiatus* was as an ornamental fish rather than for consumption.

Even though introduction activities can produce results in accordance with the aim of the introduction, it is feared that the release of introduced fish species could disrupt existing native fish populations. This case occurred in Lake Toba, where native and endemic fish species are difficult to find, such as Batak fish (genus *Neolisso-*

cheilus and *Tor*) while introduced fish such as *A. labiatus* dominate in various water bodies. The distribution map of *A. labiatus* shows that there are fluctuations in population density (ind/m^2), but this species is found in all study locations. The research results also revealed that there were phenotypic variations in *A. labiatus*, where various colour was found. If this continues, the introduced fish can get rid of the native fish due to being unable to compete for food and spawning space, or even the native fish being preyed upon by the introduced fish. In situations like this, the introduced fish grow and develop into invasive species, and can also be called biological pollutants (Syafei, 2015).

Conclusion

There are nine introduced fish species that have been established in Lake Toba, including *Amphilophus labiatus*, *Aplocheilus panchax*, *Cyprinus carpio*, *Mystacoleucus padangensis*, *Oreochromis mossambicus*, *O. niloticus*, *Poecilia reticulata*, *Puntigrus tetrazona*, and *Xiphophorus helleri*. Population density values show that *P. reticulata* has the highest average value reaching 6.02 ind/m^2, followed by *A. labiatus* 2.21 ind/m^2, M. *padangensis* 0.21 ind/m^2, *O. niloticus* 0.14 ind/m^2, *P. tetrazona* 0.08 ind/m^2, *X. helleri* 0.03 ind/m^2, and 0.01 ind/m^2 in *A. panchax*, *C. carpio*, and *O. mossambicus*, respectively. Diversity index analysis show low diversity (mean of 0.7), evenness index shows unstable community (mean of 0.46), and Simpson dominance index shows the presence of a dominant species (mean of 0.63). The results of the FIST analysis show that five introduced fish species are in the high risk category, three species have a moderate risk and one species has a low risk. *O. niloticus*, *A. labiatus*, *C. carpio*, *O. mossambicus*, and *P. reticulata* have a high risk for ichthyofauna diversity and in fact cause low diversity in Lake Toba.

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