Formosa Journal of Multidisciplinary Research (FJMR)
Vol. 5 No. 10, 2026: 3457-3472

Assessing Invasive Fish Diversity in Lake Ranu Grati, Indonesia

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A R T I C L E I N F O
Keywords: Invasive Fish, Diversity, Ranu Grati Lake, Community Structure, Spatial Distribution

Received : 25, August
Revised : 22, September
Accepted: 26, October

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A B S T R A C T
This study analyzed invasive fish species diversity in Lake Ranu Grati, Pasuruan, East Java. Sampling occurred at four stations using cast nets. Community structure was evaluated using Shannon–Wiener diversity (H'), uniformity (E), dominance (C), density (D), and relative abundance (KR). Results revealed 88 individuals across four species: Louhan (Amphilophus sp.), Tilapia (Oreochromis niloticus), Jaguar Cichlid (Parachromis managuensis), and Red Devil (Amphilophus labiatus). Values ranged for H' (0.96–1.14, low–medium), E (0.69–0.82, high), and C (0.39–0.45, low). Density peaked in vegetation areas (0.47 ind/m²) and was lowest in open water (0.10 ind/m²), showing a clumped pattern. Louhan dominated all stations (KR=55.56–63.64%). Habitat complexity and anthropogenic activity strongly influence these distribution patterns.

DOI: https://doi.org/10.55927/fjmr.v5i10.228
ISSN-E: 2829-8896
https://journalfjmr.my.id/index.php/fjmr

INTRODUCTION

Freshwater has an important role for people's lives because it provides various ecosystem services, such as food, water, and space for economic activities. The sustainability of these ecosystems faces various pressures, one of which is due to the entry of invasive fish species. Freshwater fish are among the groups that are widely introduced to various regions of the world, while freshwater ecosystems are one of the ecosystems that are vulnerable to biological invasion (Bernery et al., 2022). The entry of foreign species into a body of water can change the condition of the community through various mechanisms, including competition, predation, genetic introgression, and pathogen transmission (Britton, 2023)

The success of invasive fish in occupying new environments is influenced by their biological characteristics and introduction pathways. Analysis of 307 non-native fish species shows that aquaculture and the ornamental fish trade are introduced pathways that play a major role in the spread of fish to various regions (Bernery et al., 2024) Characteristics also determine the success of fish in adapting to new environments. Species with high fecundity, longer lifespans, and larger body sizes tend to have higher invasive capabilities. (Su et al., 2023). These conditions support introduced fish to survive and develop in new environments so that their existence can affect the composition of the fish community.

The phenomenon of invasion also occurs in various freshwater waters of the world. *Oreochromis niloticus* is reported to have the potential to threaten native fish in Lake Malawi, Africa, through competition and hybridization (J. R. Stauffer et al., 2022). Research in South America on the invasive predatory fish *Cichla ocellaris* shows that the richness of fish species in reservoirs tends to decrease over time since introduction (Franco et al., 2021). Midas cichlid (*Amphilophus citrinellus*) has been recorded as an invasive non-native fish on Bangka Island, Indonesia(Islamy et al., 2025) . Sebran *Parachromis managuensis* has also extended from West Java and Central Java to Karangkates Reservoir, East Java (Widodo et al., 2022) The Cichlidae group is the dominant group among non-native freshwater fish recorded in Indonesia, and has the potential to put pressure on native and endemic fish species(Robin et al., 2023). The spread shows that the entry of invasive fish does not only occur in certain areas, but has become an ecological problem found in various freshwater ecosystems.

One of the waters that has this condition is Lake Ranu Grati in Pasuruan Regency, East Java, Indonesia. Lake Ranu Grati is a natural lake formed due to volcanic activity, and has ecological value as a habitat for native or endemic fish, namely Lempuk fish (*Gobiopterus* sp.). This lake is located at an altitude of 6-91 m above sea level with a water area of about 198 hectares (Anitasari et al., 2024) . Lake Ranu Grati is used for various activities, including capture fisheries, fish farming, and agricultural irrigation (Khayubi et al., 2025). These waters are also used for fishery activities, including fish farming using floating net cages (Aunurohim et al., 2024). These various forms of utilization take place in waters that are also habitats for fish communities, including non-native fish.

Information on the diversity and structure of invasive fish communities in Lake Ranu Grati is still limited, especially those that describe community variations in different habitats. Differences in habitat characteristics can affect the distribution and abundance of fish species, so observations on several habitats are needed to obtain a more comprehensive picture of the community. This study examines the diversity of invasive fish in four habitats, namely floating net cage areas, tourist areas, open water, and vegetation areas. This study aims to analyze the diversity of invasive fish in different habitats in Lake Ranu Grati, Pasuruan, East Java. The results of the study are expected to provide information on the condition of invasive fish communities in different habitats in Lake Ranu Grati.

LITERATURE REVIEW

Shanon Diversity Index

The Shannon Diversity Index (H') is one of the most fundamental metrics derived from information theory to measure biodiversity in an ecological community. The concept originally developed by Claude Shannon to measure the entropy or uncertainty of information assumes that community diversity is reflected in the degree of uncertainty in predicting the species identity of randomly taken individuals (Spellerberg & Fedor, 2003). In contrast to simple species wealth measures that only calculate the total number of taxons, the Shannon Index combines two main components of community structure, namely species richness and equitable distribution of abundance between species. Mathematically, this metric is calculated based on the proportion of individual individuals of each species to the total individuals in the sample, so that the value increases as the number of species increases and the d istribution of individuals among the species becomes more even (Morris et al., 2014)

The application of the Shannon Index covers a broad spectrum of research, from macroecology to modern microbiome analysis, due to its ability to provide a sensitive picture of changes in community structure due to environmental disturbances. According to Morris et al. (2014) the main advantage of the Shannon Index lies in the moderate weight it gives to both rare and dominant species, when compared to the Simpson Index which tends to focus on dominant species. This characteristic makes the Shannon Index an ideal instrument for monitoring ecosystem recovery, measuring the impact of habitat fragmentation, and evaluating the effect of land management preferences on biodiversity. However, direct interpretation of values often requires precision due to their non-linear logarithmic nature of changes in the number of species (Jost, 2006) .

To overcome the limitations of intuitive interpretations of Shannon entropy values, the development of modern literature strongly recommends the conversion of values to effective species counts through exponential functions. Jost (2006) asserts that this exponential transformation transforms abstract entropy values into linear metrics that represent the number of species of equivalent abundance needed to produce similar entropy values. This approach allows for more objective and logical inter-community comparisons, especially when assessing the percentage of change in diversity between locations or between observation times. By integrating this effective species conversion, the Shannon Index remains one of the most robust, standardized, and relevant

analytical tools in contemporary biodiversity quantification (Morris et al., 2014; Spellerberg & Fedor, 2003).

METHODOLOGY

Research Time and Location

The research was carried out in January–July 2026 at Lake Ranu Grati, Pasuruan Regency, East Java. Samples were taken from four station points representing different habitat characteristics, namely Station 1 (cultivation area/Floating Net Cages) which is an area with high anthropogenic activity. Station 2 (tourist area), this location has a lot of human activities such as boat use and noise pollution. Station 3 (open waters/central floods) which represents water conditions with relatively minimal human disturbance. Station 4 (aquatic vegetation area) which functions as an important habitat for fish to shelter, forage, and spawn (Figure 1). The determination of the station was carried out by *purposive sampling* by considering habitat characteristics, proximity to anthropogenic pressure sources, and suspected density of invasive fish.

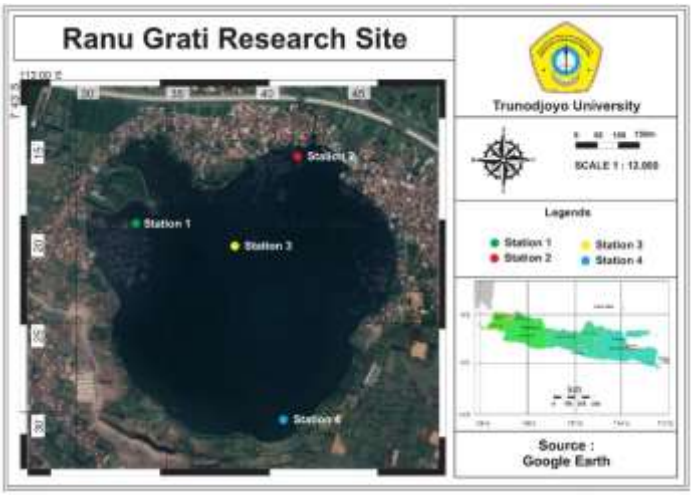

Figure 1. Map of The Research Location

Sampling

Fish samples were caught using a cast *net* with a diameter of 3 m with a net size of 1 inch and stocked 10 times at each station in accordance with the Decree of the Deputy for Fish Quarantine, Indonesian Quarantine Agency Number 08 of 2024. Each individual caught was identified based on meristic and morphometric characters with reference to the Decree of the Deputy for Fish Quarantine Number 13 of 2024, measured in length and body weight and documented. Water quality measurements (temperature, pH, and dissolved oxygen/DO) were carried out in *situ* using *a water quality checker* and pH meter.

Data Analysis

The structure of the invasive fish community at each station was analyzed using ecological indices. The Diversity (H'), diversity (E) and dominance (C) indices refer to (Nugraha et al., 2026).

Diversity Index (H')

Calculated using the Shannon–Wiener formula:

$$H' = -\Sigma\ Pi\ ln\ Pi \ldots\ldots\ldots\ldots\ldots (1)$$

$$Pi = ni/N \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

This description = the number of individuals of the ith species; N = total number of individuals of the entire species). Criteria: H' < 1 = low diversity; 1 ≤ H' ≤ 3 = medium; H' > 3 = high.

Uniformity Index (E)

Calculated by formula

$$E = H'/In\ S \ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Description H' = Shannon–Wiener index; S = number of species in the community. Criteria: E < 0.4 = low; 0.4 ≤ E ≤ 0.6 = medium; E > 0,6 = tinggi.

Dominance Index (C)

Calculated by formula:

$$C = \sum_{i=1}^{s} \left(\frac{ni}{N}\right)^2 \ldots\ldots\ldots\ldots\ldots (4)$$

Description C = dominance index; ni = jumlah individuals ke – i species; N = total number of individuals. Criteria: 0 < C ≤ 0.50 = low; 0.50 < C ≤ 0.75 = medium; 0.75 < C ≤ 1.00 = high.

Density (D)

Fish density is calculated based on the number of catches per fishing area area with the formula:

$$D = C/A \ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

$$A = \pi r^2 \ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Description C = number of individuals caught; A = area of catch. π = 3.14
r = spreading net fingers (Latumeten et al., 2022)

Relative Abundance (KR)

Calculated by formula

$$KR\ (\%) = (ni/N) \times 100\% \ldots\ldots\ldots (7)$$

Relative abundance is the ratio of the number of individuals of a species to the total number of individuals of all species at a station (Morales-Trejo et al., 2025).

RESEARCH RESULT

Results of Invasive Fish Sampling

Sampling results at four observation stations found a total of 88 invasive fish individuals consisting of four species, namely Louhan (*Amphilophus* sp.), Tilapia (*Oreochromis niloticus*), Jaguar Cichlid (*Parachromis managuensis*), and Red Devil (*Amphilophus labiatus*). Details of the number of catches per species at each station are presented in Table 1. Louhan was recorded as the species with the highest number of catches (52 individuals), followed by Tilapia (18 individuals), while Jaguar Cichlid and Red Devil were recorded as many as 9 individuals each. The highest number of catches were obtained at Station 4 (33 individuals) and lowest at Station 3 (7 individuals) (Table 1).

Table 1. Number of invasive fish catches per species at each observation station.

Types of Fish	Station 1	Station 2	Station 3	Station 4	Total
Louhan (*Amphilophus* sp.)	15	12	4	21	52
Tilapia (*Oreochromis niloticus*)	7	4	2	5	18
Jaguar Cichlid (*P. managuensis*)	2	3	1	3	9
Red Devil (*A. labiatus*)	3	2	0	4	9
Total	**27**	**21**	**7**	**33**	**88**

The percentage of catches of each species to the total is presented in Figure 1. Louhan has the highest percentage of 59% of the total catch, followed by the Tilapia (20%). The Jaguar Cichlid and Red Devil have a catch percentage of 10% each. The distribution of total catches at each station is shown in Figure 2, which shows that Station 4 has the highest number of catches, while Station 3 has the lowest number of catches among the four observation stations.

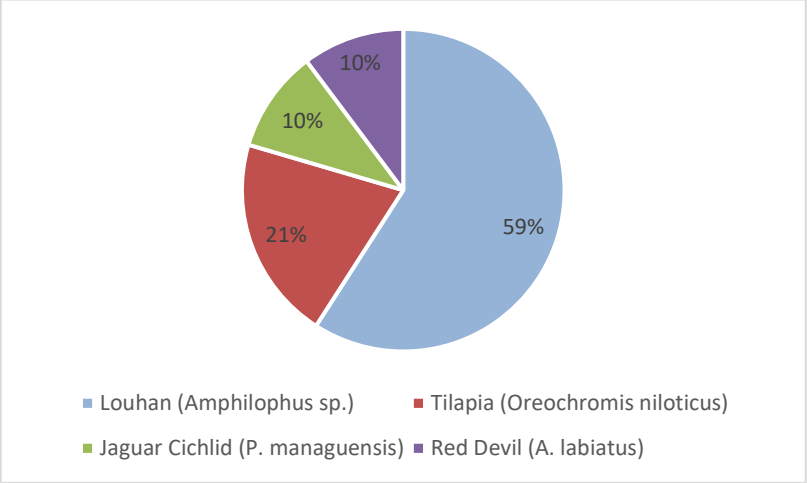

Figure 2. Proportion of Catch per Invasive Fish Species

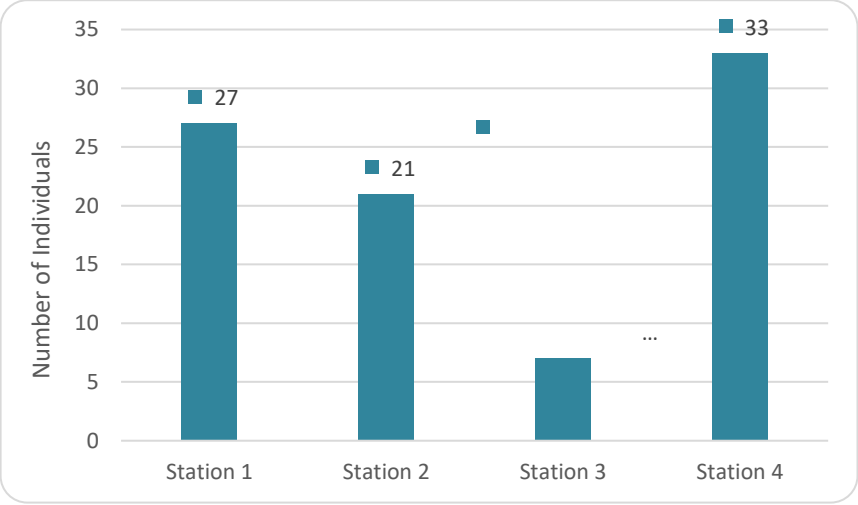

Figure 3. Total Invasive Fish Catch per Station

Community Structure: Diversity (H'), Uniformity (E), and Dominance (C) Indices

The values of the diversity (H'), uniformity (E), and dominance (C) of invasive fish at each observation station are presented in Table 2. The H' values ranged from 0.96–1.14 in the low-medium category, with the highest value at Station 2 and the lowest value at Station 3. The E value ranged from 0.69–0.82 with the high category at all stations, while the C value ranged from 0.39–0.45 with the low category at all stations, as presented in Table 2.

Table 2. Values of diversity index (H'), uniformity (E), and dominance (C) of invasive fish at each station.

Stations	H'	Category H'	E	Category E	C	Category C
1 (Floating Net Cage Area)	1.11	Medium	0.80	Height	0.39	Low
2 (Tourism)	1.14	Medium	0.82	Height	0.39	Low
3 (Open Area)	0.96	Low	0.69	Height	0.43	Low
4 (Vegetasi)	1.05	Medium	0.76	Height	0.45	Low

A comparison of the values of the three indices at each station is shown in Figure 3. Station 3 and Station 4 showed a lower value of H', but a higher value of C than Station 1 and Station 2, while the value of E was relatively consistently high across all stations.

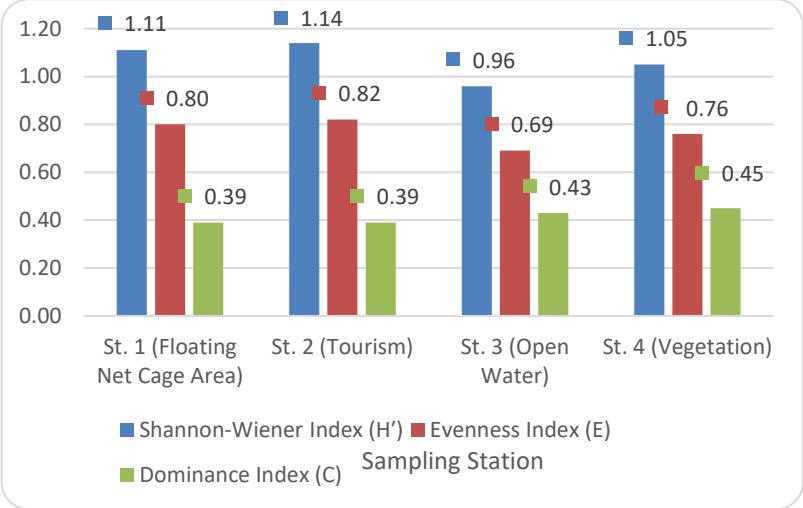

Figure 4. Graph of diversity (H'), uniformity (E), and dominance (C) invasive fish at each station.

Relative Density and Abundance Values

Table 3. Density and Relative Abundance of Invasive Fish

Stations	Density (ind/m²)	Relative Abundance (KR)			
		Louhan (%)	Tilapia (%)	Jaguar Cichlid (%)	Red Devil (%)
1 (Floating Net Cage Area)	0.38	55.56	25.93	7.41	11.11
2 (Tourism)	0.30	57.14	19.05	14.29	9.52
3 (Open Area)	0.10	57.14	28.57	14.29	0.00
4 (Vegetasi)	0.47	63.64	15.15	9.09	12.12

The highest density value was found at Station 4 (0.47 ind/m²), followed by Station 1 (0.38 ind/m²), Station 2 (0.30 ind/m²), and lowest at Station 3 (0.10 ind/m²). Louhan fish (*Amphilophus* sp.) had the highest relative abundance at all stations, ranging from 55.56–63.64%, followed by Tilapia (15.15–28.57%) and Jaguar Cichlid (7.41–19.05%), while Red Devil had the lowest relative abundance (0–14.29%) and was not found at Station 3. The relative abundance composition of each species at each station is shown in Figure 4.

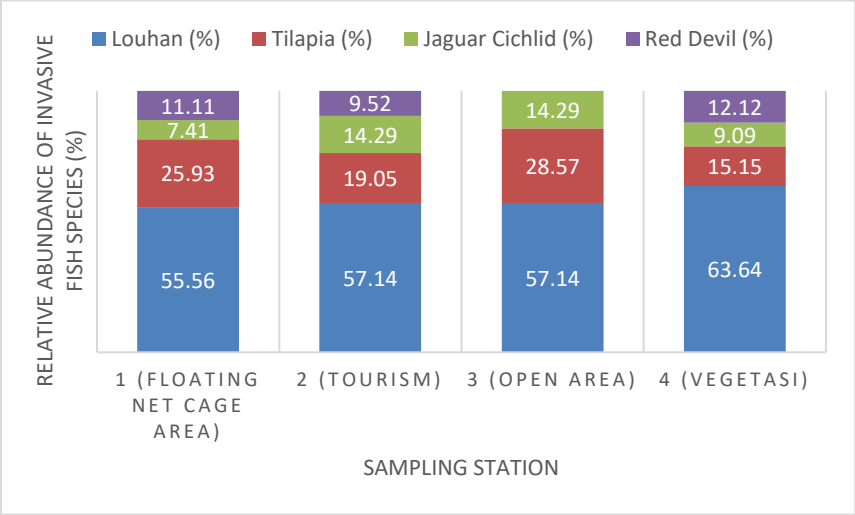

Figure 5. Graph of the Composition of the Actual Abundance of Each Station

Values of Aquatic Chemical Physics Parameters

The results of the measurement of the physico-chemical parameters of the waters at each observation station are presented in Table 4. Dissolved oxygen (DO) values ranged from 5.8–8.5 mg/L, with the highest values at Station 1 (8.5 mg/L) and lowest values at Station 2 (5.8 mg/L). The water temperature ranged from 29.1–31°C, with the highest values at Station 1 and 3 (31°C) and the lowest values at Station 4 (29.1°C). The pH values ranged from 7.5–7.8, with the highest values at Station 1 (7.8) and the lowest values at Station 4 (7.5).

Table 4. Water Quality Parameters at Each Observation Station

Stations	Lokasi	DO (mg/L)	Temperature (°C)	pH
1	Floating Net Cage Area	8.5	31.0	7.8
2	Tourism	5.8	30.5	7.7
3	Middle Ranu	6.2	31.0	7.6
4	Vegetasi	6.5	29.1	7.5

DISCUSSION

Diversity, Uniformity, and Dominance of Invasive Fish

The highest diversity index value (H') was found at Station 2/tourist area (1.14), followed by Station 1/ floating net cage area (1.11) and Station 4/vegetation (1.05), all of which were classified as medium ($1 \leq H' \leq 3$), while the lowest value was found at Station 3/open water (0.96) which was classified as

low (H' < 1). Higher diversity values at Stations 1 and 2 indicated a relatively more even composition of invasive fish species, while lower values in open waters indicated a community dominated by certain species in limited numbers. According toXie et al. (2025) , the high environmental heterogeneity of aquatic ecosystems increases fish diversity because it provides feed, shelter, spawning sites, and breeding habitats for various stages of fish life. Invasive fish diversity in Lake Ranu Grati varies between stations and is influenced by feed availability, variations in habitat structure, and human activities.

The uniformity index value (E) at all stations is relatively high (E > 0.6), ranging from 0.69 (Station 3) to 0.82 (Station 2), which indicates that the distribution of the number of individuals between invasive fish species is relatively even and that no one species is extremely dominating the number of individuals. According to Fawwaz & Rahim (2025) high uniformity index value indicates that the distribution of individuals between species is relatively even and that there are no species that dominate significantly in the community.

The value of the invasive fish dominance index at all observation stations shows a low value meaning that no invasive fish species dominate all observation stations in the waters of Lake Ranu Grati. The relatively slightly higher dominance value at Station 4 is likely related to aquatic vegetation, which provides shelter and additional food sources for fish species. According to Peterson et al. (2025) that aquatic vegetation plays an important role in aquatic ecosystems by increasing habitat complexity, providing food and shelter for various organisms, and positively correlating with the density and diversity of fish species.

Invasive fish catches at all observation stations show that Louhan fish (Amphilophus sp.) is the species with the highest number of catches. The high number of catches is thought to be related to its high adaptability to various environmental conditions. According to Abdul Gani & Sulaiman Dadiono (2024) Louhan fish are known to have high adaptability to various environmental conditions, which makes them able to dominate new ecosystems.

Density and Relative Abundance of Invasive Fish

Based on the observations, the highest density values are Station 4 and Station 1. The high density at Station 4 is likely influenced by the presence of aquatic vegetation, which plays a role in providing shelter and a source of feed for fish species. Thomaz et al. (2025), explain that macrophytes act as a physical barrier that modifies the abiotic environment so as to create conditions that fish prefer, such as higher oxygen concentrations. The habitat complexity provided by macrophytes also benefits fish by providing protection from predation and serving as a breeding ground, spawning substrate, and nursery habitat for larvae and juveniles, in addition to providing a source of feed such as periphytons and invertebrates that are attached to structurally complex habitats.

The high density at Station 1 is suspected to be influenced by floating net cage cultivation activities that produce residual feed and organic matter, thereby increasing the availability of food sources for invasive fish while potentially reducing water quality. Okechi et al. (2025) in their study in Lake Victoria

explained that waste from feed residues and fish excretion that accumulates around the cages causes nutrient enrichment in the waters, which can trigger increased nitrogen and phosphorus levels and trigger eutrophication and harmful algal blooms, which further lowers dissolved oxygen levels. Low oxygen conditions not only threaten the survival of farmed fish but also harm native fish populations, reduce biodiversity, and disrupt food webs.

The relative abundance value of the observation results is known that the Louhan Fish has the highest relative abundance at all observation stations, indicating that this species dominates the invasive fish community in the waters of Lake Ranu Grati. According to Škornik & Pipenbaher (2024) dominant species generally have a higher tolerance to environmental pressures as well as a competitive advantage in obtaining resources, thus playing a role in determining the structure of the community. This dominance has the potential to cause competition with local species in resource utilization. Shuai & Li (2022) found that tilapia invasion causes high trophic niche overlap with native species, forcing native fish to seek alternative food sources and suppressing their trophic niches, thereby disrupting the trophic structure of the overall fish community These findings are in line with the results of Oba & Doi (2026) who show that the higher the diversity of invasive fish species in a watershed, the more uniform the composition of native fish communities between locations. A pattern that indicates a process of biotic homogenization, in which invasive species effectively eliminate native fish community differences typically formed by local environmental conditions.

Physico-Chemical Parameters of Waters

The results of water quality measurements showed that DO values ranged from 5.8–8.5 mg/L, with the highest values at Station 1 (floating net cage area) and the lowest at Station 2 (tourist areas). DO is an absolute prerequisite for the survival of fish and plays an important role in their growth, development, and physiological processes; decreased levels of DO can trigger stress, tissue damage, oxidative stress, decreased immune function, and metabolic disorders in fish (Shuai & Li, 2022).

The temperature of the waters of Lake Ranu Grati ranges from 29.1–31°C, corresponding to the normal range of tropical waters. Temperature significantly affects the metabolic rate and physiological processes of fish, including diet and secretion of digestive hormones such as cholecystokinin (Volkoff & Rønnestad, 2020). Relatively high temperatures at the time of sampling (during the day) have the potential to increase the metabolic rate of fish while decreasing the solubility of oxygen in the water.

pH values range from 7.5–7.8, which is optimal for most freshwater fish that generally tolerate a range of 6.5–9.0 (Menon et al., 2023). The pH stability of all stations indicates that the waters still support the basic physiological processes of the fish, including ion balance and enzymatic activity, as significant changes in pH can trigger oxidative stress as well as disturbances in the fish's immune system.

Invasive Fish Introduction Pathway

As a result of interviews with the surrounding community, invasive fish found in Lake Ranu Grati enter through human activities, especially fish farming activities using Floating Net Cages and releasing fish into the waters. The introduction route through aquaculture activities and the trade of ornamental fish is one of the main routes for the entry of non-native fish into freshwater ecosystems globally (Bernery et al., 2024).

Louhan fish (Amphilophus sp.) is suspected to have entered Lake Ranu Grati through ornamental fish cultivation activities using Floating Net Cage Area. Based on the results of the interviews, the damage to the nets caused the fish to be released into natural waters. The ornamental fish trade route is known to play a role in the introduction and spread of non-native fish into natural aquatic ecosystems (Vezi et al., 2024).

Tilapia (Oreochromis niloticus) is suspected to have entered the waters of Lake Ranu Grati through cultivation activities using Floating Net Cage Area. Based on interviews with cultivators, fish can be released during the harvesting process or due to net damage. Globally, O. niloticus has been introduced to various countries, especially for the benefit of aquaculture and fisheries development (El-Sayed & Fitzsimmons, 2023).

The Cichlid jaguar (Parachromis managuensis) is suspected of entering Lake Ranu Grati through deliberate release by the community. Based on the results of the interview, the fish was released with the aim of controlling the population of Louhan fish in the waters of Lake Ranu Grati. The release of fish raised as ornamental fish into the natural aquatic environment is one of the mechanisms that can lead to the entry of non-native species into new ecosystems (Atalah et al., 2022).

Red Devil fish (Amphilophus labiatus) is suspected to have entered Lake Ranu Grati through ornamental fish cultivation activities using Floating Net Cage Area. Based on the results of the interview, the damage to the cage caused the fish to escape into natural waters. Fish escape from ornamental aquaculture activities is one of the routes for the introduction of non-native fish into natural aquatic ecosystems (Luduvice et al., 2023).

Based on the results of interviews and field findings, the introduction of invasive fish in Lake Ranu Grati is related to human activities through two main routes, namely the release of fish into natural waters and the release of fish from aquaculture activities using Floating Net Cage Area. These conditions are in line with global studies that show that aquaculture, ornamental fish trade, and intentional or accidental releases are important pathways for the introduction of non-native fish into aquatic ecosystems (Bernery et al., 2024) .

CONCLUSIONS AND RECOMMENDATIONS

The diversity of invasive fish species in Lake Ranu Grati is relatively low to moderate (H' = 0.96–1.14), with four species identified: Louhan (Amphilophus sp.), Tilapia (Oreochromis niloticus), Jaguar Cichlid (Parachromis managuensis), and Red Devil (Amphilophus labiatus) out of a total of 88 individuals. Uniformity is relatively high (E = 0.69–0.82) and dominance is relatively low (C = 0.39–0.45), but Louhan consistently dominates relative abundance across

stations (55.56–63.64%). The highest densities were found in vegetation areas (0.47 ind/m²) and floating net cage areas (0.38 ind/m²), with clustering distribution patterns that were more influenced by habitat complexity and anthropogenic activity than variations in water quality between stations.

Due to the high density of invasive fish in the vegetation and Floating Net Cage Areas, it is necessary to periodically monitor the structure of the invasive fish community needs to be focused on these two habitat types as priority control areas. Further research is recommended to combine data on the structure of this community with a study of trophic interactions to assess the ecological impact of invasive fish on Lempuk endemic fish, as well as develop an ecosystem management strategy that is integrated between invasive fish population control and supervision of new introduction routes from aquaculture activities and the release of ornamental fish.

ADVANCED RESEARCH

To build upon these findings, future research should implement multi-season longitudinal monitoring to evaluate temporal variations in invasive fish densities, reproductive cycles, and spatial shifts driven by changing water levels and human activities. Concurrently, integrating stomach content analysis with stable isotope analysis (δ^{13}C and δ^{15}N) on *Amphilophus* sp. and other invasive cichlids will quantify direct predation and food web competition threatening the endemic Lempuk fish. Complementing these ecological assessments, socio-ecological studies targeting floating net cage aquaculture and the ornamental fish trade are necessary to trace escape vectors and introduction pathways into Lake Ranu Grati. Ultimately, these datasets should feed into bio-economic and population control models to evaluate the efficacy of selective removal strategies such as targeted gillnetting or trapping in high-density vegetation and net cage zones integrated with community-based oversight and biosecurity regulations.

ACKNOWLEDGMENT

The author would like to thank the East Java Animal, Fish and Plant Quarantine Center for supporting this research through the provision of laboratory facilities. The author also thanks all individuals who assisted with fish sampling and other research activities.

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