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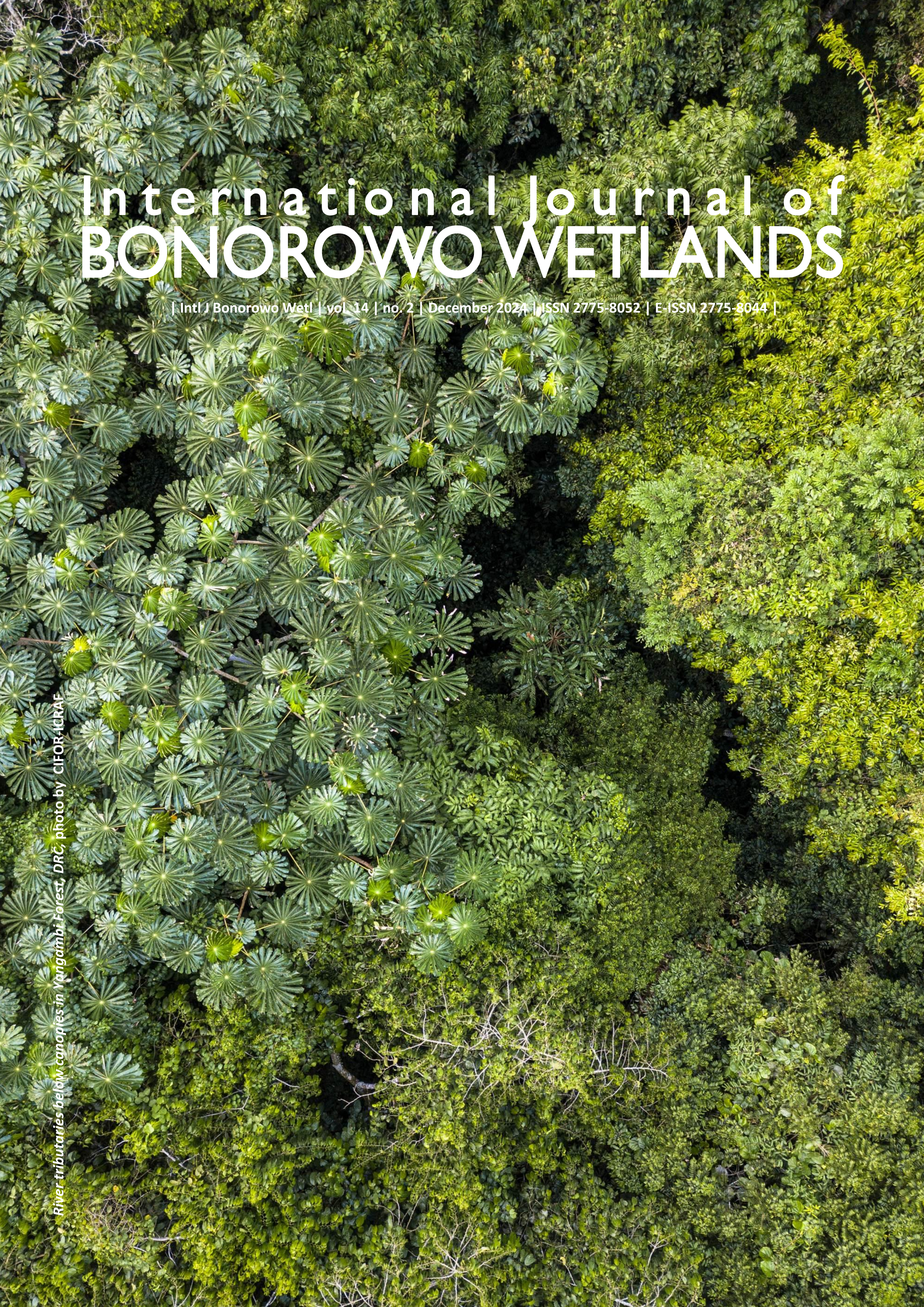

River tributaries below canopies in Yangambi Forest, DRC, photo by CIFOR-ICRAF

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OFFICE ADDRESS
Forest and Land Fire Laboratory, Department of Silviculture, Faculty of Forestry, Institut Pertanian Bogor.
Jl. Lingkar Akademik Kampus IPB Dramaga, Bogor 16680, West Java, Indonesia. Tel.: +62 251 8626806, Fax.: +62 251 8626886;
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Journal:

Saharjo BH, Nurhayati AD. 2006. Domination and composition structure change at hemic peat natural regeneration following burning; a case study in Pelalawan, Riau Province. Biodiversitas 7: 154-158. DOI: 10.13057/biodiv/d070213.

The usage of "et al." in long author lists will also be accepted:

Smith J, Jones M Jr, Houghton L et al. 1999. Future of health insurance. N Engl J Med 965: 325-329. DOI: 10.10007/s002149800025.

Book:

Rai MK, Carpinella C. 2006. Naturally Occurring Bioactive Compounds. Elsevier, Amsterdam.

Chapter in the book:

Webb CO, Cannon CH, Davies SJ. 2008. Ecological organization, biogeography, and the phylogenetic structure of rainforest tree communities. In: Carson W, Schnitzer S (eds.). Tropical Forest Community Ecology. Wiley-Blackwell, New York.

Abstract:

Assaeed AM. 2007. Seed production and dispersal of *Rhazya stricta*. 50th annual symposium of the International Association for Vegetation Science, Swansea, UK, 23-27 July 2007.

Proceeding:

Alikodra HS. 2000. Biodiversity for development of local autonomous government. In: Setyawan AD, Sutarno (eds.). Toward Mount Lawu National Park; Proceeding of National Seminary and Workshop on Biodiversity Conservation to Protect and Save Germplasm in Java Island. Universitas Sebelas Maret, Surakarta, 17-20 July 2000. [Indonesian]

Thesis, Dissertation:

Sugiyarto. 2004. Soil Macro-invertebrates Diversity and Inter-Cropping Plants Productivity in Agroforestry System based on Sengon. [Dissertation]. Universitas Brawijaya, Malang. [Indonesian]

Information from the internet:

Balagadde FK, Song H, Ozaki J, Collins CH, Barnet M, Arnold FH, Quake SR, You L. 2008. A synthetic *Escherichia coli* predator-prey ecosystem. Mol Syst Biol 4: 187. DOI: 10.1038/msb.2008.24. www.molecularsystembiology.com.

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Morphological identification of mosquito species in Takur Adu'a and Yakasai, Dutse Local Government Area, Jigawa State, Nigeria

SANI ADO UMAR[1,♥], RAMGOPAL DHAKAR[1], HAMIMA SURAJ USMAN[2], MUSTAPHA SULAIMAN[3], MUBARAK SA'IDU[1], MADANIYYU SULAIMAN YAHAYA[4], AHMAD SADI SHITU[1], HABIB MUMAMMAD USMAN[5]

[1]Department of Life Science, Mewar University. NH - 48 Gangrar Chittorgarh, Rajasthan-312901, India. Tel.: +91-1471-285451/52, ♥email: saniadoumar@gmail.com

[2]Department of Biological Science, Federal University Dutse. Ibrahim Aliyu Way Bye-Pass, Dutse, Nigeria

[3]Department of Chemistry, Mewar University. NH - 48 Gangrar Chittorgarh, Rajasthan-312901, India

[4]Department of Mechanical Engineering, Mewar University. NH - 48 Gangrar Chittorgarh, Rajasthan-312901, India

[5]Department of Electrical Engineering, Mewar University. NH - 48 Gangrar Chittorgarh, Rajasthan-312901, India

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Abstract. *Umar SA, Dhakar R, Usman HS, Sulaiman M, Sa'idu M, Yahaya MS, Shitu AS, Usman HM. 2024. Morphological identification of mosquito species in Takur Adu'a and Yakasai, Dutse Local Government Area, Jigawa State, Nigeria. Intl J Bonorowo Wetlands 14: 57-65.* Mosquitoes, major vectors for various diseases, pose significant public health challenges worldwide. This study focuses on identifying and analyzing mosquito species in Takur Adu'a and Yakasai Areas of Jigawa State, Nigeria. Located in Northwestern Nigeria with Dutse as its capital, Jigawa State borders Kano, Katsina, Bauchi, Yobe, and the Zinder Region in Niger, facilitating cross-border trade. The major tribes are Hausa, Fulani, and Kanuri. Mosquito collection was conducted early in the morning using a prepared environment and spraying method. Morphological identification of differentiating species of mosquito are by palps, proboscis, wing patterns, body shape, and resting positions. In Takur Adu'a and Yakasai, a total of 449 mosquitoes were collected, 278 from Takur Adu'a and 171 from Yakasai. *Aedes* species included 21 females and 29 males; *Culex* had 82 females and 52 males; *Anopheles* had 35 females and 24 males; *Anopheles gambiae* had 7 females and 4 males; and non *A. gambiae* had 8 females and 16 males. *Culex* mosquitoes were the most dominant, followed by *Aedes* and *Anopheles*, with 71.2% being fed, indicating significant feeding activity and potential disease transmission. In Yakasai, Aedes species included 17 females and 12 males, *Culex* had 42 females and 50 males, *Anopheles* had 12 females and 16 males, *A. gambiae* had 8 females and 6 males, and non *A. gambiae* had 5 females and 3 males. The study identify only morphospecies but *A. gambiae* and non *A. gambiae* are different morphospecies but in the same genus. *Culex* was the most prevalent species, with 57.9% fed, highlighting a substantial risk of disease transmission. The study also assessed respondents' knowledge of mosquito bite prevention, finding significant awareness levels, though gaps remained, and necessitating targeted educational campaigns. Identifying multiple mosquito genera and species emphasizes the value of molecular methods for mosquito identification. The findings reveal a dominant presence of *Culex* mosquitoes and a high percentage of fed mosquitoes, indicating significant disease transmission risks. Continuous education and effective vector control strategies are crucial to mitigate health risks in Jigawa State.

Keywords: Blood-feeding insect, mosquito classifications, physical characterization, vector-borne illness

INTRODUCTION

Mosquitoes are regarded as one of humanity's biggest enemies, because of the tremendous misery and fatalities brought on by the diseases they spread. They are essential to the epidemiology of important public health insect-borne diseases, particularly in regions with a variety of lakes and rivers that facilitate their reproduction. Mosquitoes are a nuisance when they bite and can spread infectious diseases due to the range of water settings in which they can breed (Girard et al. 2021). The female *Anopheles* mosquito is the cause of malaria (Girard et al. 2021). Because of their widespread distribution, ability to transmit illness, variety, and ongoing infection, mosquitoes are the primary carriers of several illnesses, such as dengue fever, malaria, and the Zika Virus (Magalhaes et al. 2019). Many species prefer habitats with vegetation, while some breed in open, sunlit pools, and a few species use tree holes or the lower parts of the leaves of particular trees. Numerous factors, such as temperature of the water, movements, cover of vegetation, source of water, and depth, impact the development and dissemination of mosquito larvae in aquatic surroundings (Medeiros-Sousa et al. 2020). Nutrition also has a significant impact on the reproductive abilities of female mosquitoes and their larval growth, suggesting that deficiency in food during both adult and larval periods could influence their ability for reproduction (Dittmer and Gabrieli 2020). Since mosquitoes begin their lives as eggs, the procedures of laying eggs, larval growth, as well as other developing processes that occur in mosquito environments are crucial in determining the abundance and distribution of mosquitoes (Dittmer and Gabrieli 2020). Since mosquitos actively seek acceptable environments instead of haphazardly occupying them, collecting larval mosquitoes aids in estimating mosquito needs for site selection and survival. The developmental progress of growing adults is influenced by the selection of habitat, which dictates distribution patterns, density, development time, body size, and survival (Djihinto et al. 2022).

Traditional mosquito prevention methods include indirect capturing using Ultra-Violet (UV) light and direct poisoning with insecticidal sprays and repellents. However, continued use of these techniques may result in insecticide tolerance and have a negative impact on the natural world and human well-being (Kitching 2020). According to (Rolff et al. 2019), mosquito species are holometabolic insects that go through aquatic immature phases (larvae and pupae) before emerging as terrestrial adults. The intestinal epithelial is essential to the physiology and function of mosquitoes as adults, which differ physically from larvae (Hixson et al. 2021). Widespread malaria is caused by a number of mosquito species, including *Aedes*, *Culex*, *Anopheles*, and *Mansonia* (Santi et al. 2021). While *Culex* mosquitoes are frequent transmitters of diseases like West Nile Virus, *Aedes* mosquitoes are significant arbovirus vectors of chikungunya, rift vally fever and Mayaro virus (Velu et al. 2021). Although a few investigations have documented the virome for individual mosquitoes, research has attempted to sequence the virome of these genera (Shi et al. 2019).

In Jigawa State, Nigeria, the identification of mosquito species and their participation in malaria transmission has been the subject of numerous studies. Jigawa State is a state in northwest Nigeria. It is bordered to the west by Kano and Katsina, to the east by Bauchi, to the northeast by Yobe, and the north by an international boundary with the Zinder Region of Niger. This arrangement facilitates cross-border trade. Major tribes, including the Hausa, Fulani, and Kanuri, live in the state with Dutse as its capital. Investigators have mapped the distribution of mosquito species and studied their activity and breeding patterns in local governments in Jigawa State and nearby states like Kano, Katsina, and Bauchi. The results of these investigations have provided important information regarding the types of mosquitoes that are common in various areas (Chukwuekezie et al. 2020). *Anopheles* mosquitoes, the main malaria vectors, are quite prevalent in Kano, particularly in peri-urban and rural areas with standing water. The extensive *Aedes* mosquito population in urban areas of Katsina suggested possible dangers for illnesses other than malaria, like dengue fever. According to Shi et al. (2019), Bauchi's research revealed that *Culex* mosquitoes, which are abundant in densely populated areas and thrive in contaminated water bodies, are a significant factor in the spread of filariasis and malaria.

This study aims to determine the types of mosquitoes that are present in the Takur Adu'a and Yakasai Regions of Jigawa State's Dutse Local Government Area, Nigeria and evaluate their contribution to the spread of disease. The study highlights the necessity of ongoing education, successful vector control methods, and creative solutions to lower the health concerns brought on by mosquito populations. By gaining an understanding of the distribution and behavior of mosquito species in Takur Adu'a and Yakasai, this research can help create targeted interventions to lessen the effect of mosquito-borne diseases in Jigawa State.

MATERIALS AND METHODS

Study area

Jigawa State is one of the 36 states that constitute the Federal Republic of Nigeria, it is a state of central northern Nigeria with Dutse as the state capital. It's located in the northwestern part of the country. Kano and Katsina states shared a border with Jigawa to the west, Bauchi to the east, and Yobe to the northeast. To the north, Jigawa shared an international border with the Zindar Region in the Republic of Niger, which is a unique opportunity for cross-border trading activities. The government readily took advantage of this by initiating and establishing a trade zone at the border town of Maigatari to the country of Niger; Hausa, Fulani, and Kanuri are the major tribes in the state. Dutse; latitude and longitude 12.4382° N, 8.6161° E.

Sample collection

All the equipment was gathered, the homes where the PSC would be conducted were identified, the head of the household was notified, and permissions were received, ideally the day before collection; samples were collected at different sites in both Takur Adu'a and Yakasai Areas. Materials such as Forceps, Petri dish, White sheet, Hand glove, Pyrethrum Spray Catch (PSC) have been used for sample collection. PSC should have been conducted early in the morning, approximately 5 am to 8 am. The house was prepared early in the morning, with all occupants and animals having remained outside. Exposed food and drinking water were covered, and any water pots that could not be moved were covered. White sheets (fabric) were spread over the entire floor, over the bed, and over furniture; all windows and doors were closed. The surfaces that mosquitoes may have been resting on, including the walls and ceiling, were sprayed (Pryce et al. 2022).

After the entire room has been sprayed, the operator immediately leaves the house and ensures the door remains closed for 10 minutes while waiting for the mosquitoes to be eradicated. Therefore, to contain the mosquitoes, the door was closed, starting from the doorway, and the sheets were taken one at a time from the corners. Each mosquito was quickly placed in a petri dish (Figure 1) until processed and stored long-term (Montoya et al. 2022).

Morphological identification of mosquitoes

The keys of Gillies and Coetzee (2019) were used for the identification of *Anopheles* species, while the identification key of Gilleth (2015) was used for *Culex* identification and Aedes mosquitoes. Mosquitoes were identified morphologically by using a microscope; male mosquitoes are identified by their feathery antennae and beard, while female ones are identified by the absence of feathery antennae and beard (Figure 2). *Anopheles* mosquitoes were identified by the palp, which is as long as the proboscis and pointed, and by the number, length, and arrangement of the dark and pale scales in small blocks on the veins of the wings. Male and female *Anopheles* mosquitoes were ide ntified by examination of antennae, in which those with feathery (plumose) appearance are males and those with only short and inconspicuous antennal hairs are females (Figure 2) (Supriyono et al. 2022).

The fed and unfed mosquitoes were identified under a microscope. Fed mosquitoes were identified by observing their stomachs; the stomach of the fed mosquito was red due to the presence of blood, while the unfed mosquito's stomach was white due to the absence of blood (Figure 3). Most mosquitoes that feed on blood are females. They need the nutrients from blood to produce eggs.

Culex mosquitoes have blunt abdomens, and their wings are usually clear without spots (Kang et al. 2020). Their body is usually brownish, and the palps (sensory organs near the mouthparts) are shorter than the proboscis (elongated mouthpart). The larvae rest parallel to the water surface; *Aedes* mosquitoes are known for their striking black and white markings on the body and legs. They have a pointed abdomen and their wings are also clear (Figure 2). *Aedes* mosquitoes are typically smaller and have shorter palps compared to the proboscis. They often have a more aggressive appearance and are commonly associated with daytime biting (Tallon et al. 2019). *Anopheles* mosquitoes, particularly *Anopheles gambiae*, are distinguishable by their palps, which are as long as their proboscis (Supriyono et al. 2022). Their wings often have dark and pale spots on the veins, and they have slender bodies compared to *Culex* and *Aedes*. When at rest, their bodies form an angle with the surface they are resting on rather than lying flat. Their larvae lie parallel to the water surface, but they have a unique head-down position (Figure 1). Non *A. gambiae* mosquitoes share many features with *A. gambiae*; both species their wings that often have dark and pale spots on the veins, and they have more slender body in corresponding to other species. The main difference between *A. gambiae* and non *A. gambiae* is the egg-laying pattern; the mosquito's life cycle starts from egg to adult (Figure 4).

Figure 1. Sample collection of mosquitoes

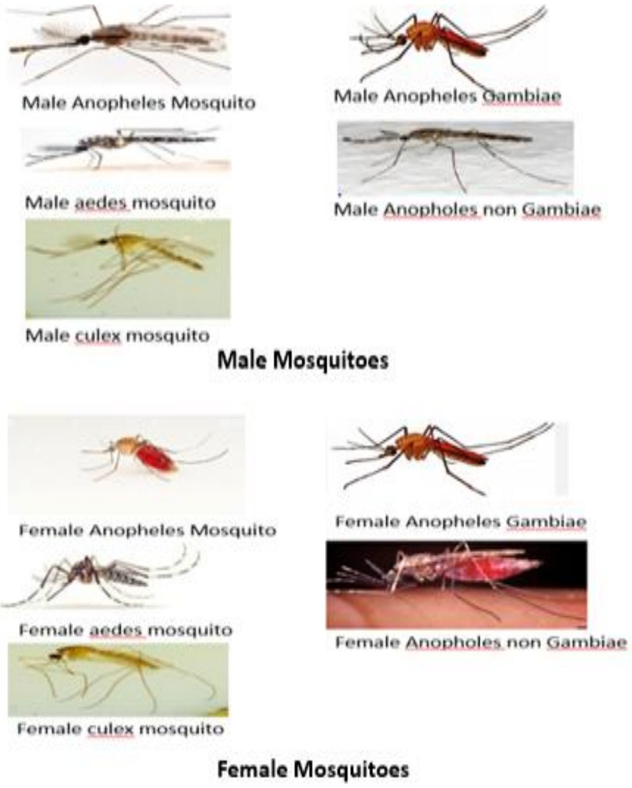

Figure 2. Male and female morphological identification of mosquito species

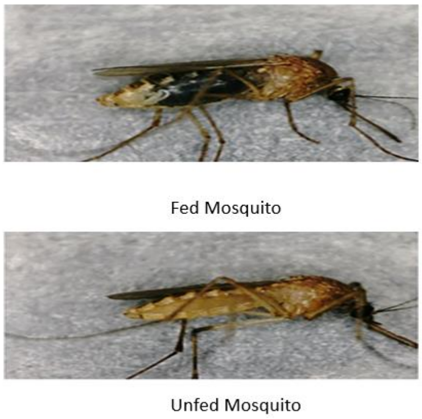

Figure 3. Fed and unfed mosquito

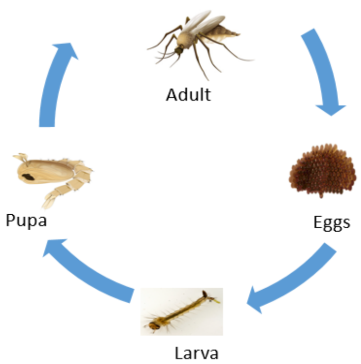

Figure 4. Mosquito life cycle

The main features to look for are the wing patterns, body shape, and resting positions. Male and female *Anopheles* mosquitoes can be differentiated based on their antennae; those with feathery antennae are male, while those with short antennae are female (Coetzee 2020). *Culex* has clear wings and a blunt abdomen, distinctive black and white markings, and a pointed abdomen. The *A. gambiae* has spotted wings and long palps, while non *A. gambiae* species have dark and pale spots on the veins (Namgay et al. 2020).

In order to gather information on the methods employed by individuals to prevent mosquito bites, a structured questionnaire was designed and administered to the respondents. The primary question asked was: "What method do you use to prevent mosquito bites?" Five possible preventive measures were presented as options for the respondents to choose from: (i) Use of bed nets, (ii) Use of mosquito repellent, (iii) Use of insecticide, (iv) Use of screens on windows and doors, (v) Use of fans. Respondents were instructed to select one or more of the options that they practiced regularly. The questionnaire was distributed to a sample population of individuals from the Takur adu'a and Yakasai area of Jigawa State, and responses were recorded for further analysis.

RESULTS AND DISCUSSION

This study aimed at identifying mosquito species in two selected areas, Takur Adu'a and Yakasai. These areas were chosen due to their environmental conditions—numerous drainages, farming activities, and sewage systems—which create ideal breeding grounds for mosquitoes, leading to a higher population density. A total of 449 mosquito samples were collected, with 278 samples from Takur Adu'a and 171 from Yakasai. This sampling effort reflects the researchers' intent to gather a comprehensive representation of mosquito species in these regions. The significant number of samples enables a robust analysis of the mosquito population and allows for more accurate identification of species, which is crucial in understanding potential health risks in the community, especially in relation to mosquito-borne diseases. The differences in sample sizes between the two areas may indicate varying environmental factors that influence mosquito breeding, such as water sources, human activities, and waste management.

Discussion

In Takur Adu'a and Yakasai Areas, 449 mosquitoes' species were collected; 278 were collected from Takur Adu'a, and 171 were collected and morphologically classified from Jigawa State's Yakasai Region. Table 1 shows the frequency and proportion of several mosquito species, broken down by sex, that are found in the Takur Adu'a Area. *Aedes, Culex, Anopheles, A. gambiae,* and non *A. gambiae* are among the species that were observed; mosquitoes were collected at three sites in Takur Adu'a, among which 94 mosquitoes were collected from site A, 114 from site B, and 70 from site C. There were 50 mosquitoes altogether, consisting of 21 females and 29 males, belonging to the *Aedes* species. This signifies an observable and impactful occurrence in the surrounding area, augmenting the total count of mosquitoes. A stable breeding population may be indicated by the reasonably balanced ratio of females to males of *Aedes* mosquitoes (O'Leary and Adelman 2020). The greatest frequency was found in *Culex* mosquitoes, with 82 females and 52 males totaling 134 individuals. This dominance implies that the most common species of mosquitoes in the area are *Culex* mosquitoes. Since female mosquitoes are largely responsible for biting and spreading illnesses, the higher number of females compared to males may have repercussions for disease transmission (Xia et al. 2021). There were 24 male and 35 female mosquitoes in the *Anopheles* species. Considering that many *Anopheles* mosquitoes are malaria vectors, this species is vital to public health awareness (Djihinto et al. 2022). There may be a risk of malaria transmission due to the slightly increased number of females (Sumner et al. 2021). There were 7 female and 4 male *A. gambiae* mosquitoes in all. The *A. gambiae*, which is well-known for its effectiveness in spreading malaria, is present but in very small numbers (Ahadji-Dabla et al. 2019). It may be required to implement ongoing control and monitoring procedures to stop possible outbreaks. Finally, there were a total of 24 species in the non *A. gambiae* category, comprising 8 females and 16 males. In comparison to other species, there may be a distinct pattern in the population dynamics or breeding behavior indicated by the greater proportion of males.

This study revealed that *Aedes* and *Anopheles* mosquitoes are the next most common species in the Takur Adu'a Area, after *Culex* mosquitoes. The information emphasizes how crucial it is to concentrate on *Culex* control strategies while also taking into account *Anopheles* species—particularly *A. gambiae*—and their implications for public health awareness. The distribution by gender shows that there are more females than males in each species, highlighting the possibility of disease transmission and the urgent need for immediate, focused vector control measures. Table 1 also gives the Takur Adu'a Areas fed and unfed mosquito frequency and percentage of occurrence. The information makes a distinction between mosquitoes that have been fed (fed blood) and those that have not (unfed blood). Fed and unfed mosquitoes were collected and identified from the three sites: site A 76 mosquitoes were fed; site B, 58, and site C, 64 mosquitoes were identified; unfed mosquitoes from site A were 18, and site B, 56 and 6 from site C.

Table 1 shows that 198 mosquitoes, or 71.2% of the entire mosquito population measured, were noted as fed. There is likely a significant amount of host-seeking and feeding activity in the area based on the high percentage of fed mosquitoes. Given that female mosquitoes are frequently the ones who transmit viruses through their bites, the prevalence of such a high percentage of fed insects plays a major role in the possible transmission of diseases carried by mosquitoes. However, 80 mosquitoes, or 28.8% of the overall population, were found to be unfed.

Even while this percentage is lower than that of fed mosquitoes, it nevertheless indicates a sizable component of insects that have not yet consumed blood. If these unfed mosquitoes get sick after feeding, they may aggressively seek out humans, increasing the risk of bites and disease transmission (Shaw et al. 2020).

Table 1. Frequency and percentage of occurrence of the mosquito species in Takur Adu'a Area, Jigawa State, Nigeria

Species	***Aedes***	***Culex***	***Anopheles***	***Anopheles gambiae***	**Non *Anopheles gambiae***
Female	21	82	35	7	8
Male	29	52	24	4	16
Total	50	134	59	11	24

Species	**Sites of collection**			
	A	**B**	**C**	**Total**
Aedes	14	26	10	50
Culex	52	47	35	134
Anopheles	17	24	18	59
Anopheles gambiae	3	6	2	11
Non *Anopheles gambiae*	8	11	5	24
Total	94	114	70	278

Frequency and percentage of occurrence of fed and unfed mosquitoes in Takur Adu'a Area

Species	**Frequency**	**Percentage (%)**
Fed	198	71.2
Unfed	80	28.8
Total	278	100

Species	**Collection site**	**Frequency**	**Percentage (%)**
Fed	Site A	76	27.3
	Site B	58	20.9
	Site C	64	23.0
Unfed	Site A	18	6.5
	Site B	56	20.1
	Site C	6	2.2
Total	3	278	100

Table 2. Frequency and percentage of occurrence of the mosquito species in the Yakasai Area, Jigawa State, Nigeria

Species	***Aedes***	***Culex***	***Anopheles***	***Anopheles gambiae***	**Non *Anopheles gambiae***
Female	17	42	12	8	5
Male	12	50	16	6	3
Total	29	92	28	14	8

Species	**Sites of collection**			
	A	**B**	**C**	**Total**
Aedes	11	8	10	29
Culex	38	27	27	92
Anopheles	9	12	7	28
Anopheles gambiae	4	7	3	14
Non *Anopheles gambiae*	3	4	1	8
Total	65	58	48	171

Frequency and percentage of occurrence of fed and unfed mosquitoes in Yakasai Area

Species	**Frequency**	**Percentage (%)**
Fed	99	57.9
Unfed	72	42.1
Total	171	100

Species	**Collection site**	**Frequency**	**Percentage (%)**
Fed	Site A	38	22.2
	Site B	27	15.8
	Site C	34	19.9
Unfed	Site A	27	15.8
	Site B	31	18.1
	Site C	14	8.2
Total	3	171	100

The study showed that 278 mosquitoes were scanned across the Takur Adu'a region, with the majority found to be fed. This indicates the presence of large vectors and the risk of spreading diseases such as dengue fever, malaria, and other mosquito-borne diseases. Hence, public health officials, researchers, and policymakers must take the lead in monitoring and managing mosquito populations in these areas. By reducing the number of feeding mosquitoes, we can effectively manage and minimize the health hazards associated with mosquito bites.

Table 2 presents the frequency and proportion of several mosquito species, broken down by sex, that are found in Yakasai Area. *Aedes*, *Culex*, *Anopheles*, *A. gambiae*, and non *A. gambiae* are among the species that were found. In Yakasai Area, mosquitoes were collected at three sites: site A, 65 mosquitoes were collected from all species; site B, 58, and site C, 48 mosquitoes were collected from all species.

There were a total of 29 mosquitoes, comprising 12 male and 17 female members of the *Aedes* species. Although not the most common species, this mosquito species makes up quite a large portion of the local mosquito population. According to Gouveia-Oliveira and Pedersen (2020), the generally balanced ratio of males to females points to a stable population dynamic. This stability can have significant consequences for the spread of disease, as a balanced ratio means more potential carriers for diseases like dengue fever and Zika. *Aedes* mosquitoes are known to carry these diseases. The most frequent mosquito species was *Culex*, with 42 females and 50 males totaling 92 individuals. This suggests that the most common species in Yakasai Region is *Culex*. The slightly larger male-to-female ratio may have an impact on population dynamics and total breeding. Because *Culex* mosquitoes are important carriers of diseases, including filariasis and the West Nile Virus, monitoring and control of this species is essential. There were 12 female and 16 male *Anopheles* mosquitoes in the species. This species is important from the standpoint of public health because *Anopheles* mosquitoes are the main carriers of malaria. The greater proportion of males than females may indicate a shift in the population's structure or recent environmental changes that have an impact on mosquito breeding habits. There were 8 female and 6 male *A. gambiae* mosquitoes in total. The *A. gambiae* is present in relatively small quantities, but because of how well it spreads malaria, it is important. The nearly equal proportion of men and females points to a stable population, which calls for ongoing monitoring and preventative efforts to lower the risk of malaria. There were 3 males and 5 females in the non *A. gambiae* group, for a total of 8 mosquitoes. The fact that there are fewer non *A. gambiae* mosquitoes than other species shows that they are the least common. They should not be disregarded, though, as they may nevertheless raise the risk of mosquito-borne illness in general.

Table 3. Distribution of respondents based on their knowledge of practices for mosquito bite prevention in Takur Adu'a and Yakasai Area of Jigawa State, Nigeria

Responses	Frequency	Percentage (%)
Bed net	30	42.9
Use of repellent	10	14.3
Use of insecticides	15	21.4
Use of screens in windows and doors	10	14.3
Use of fan	5	7.1
Total	70	100

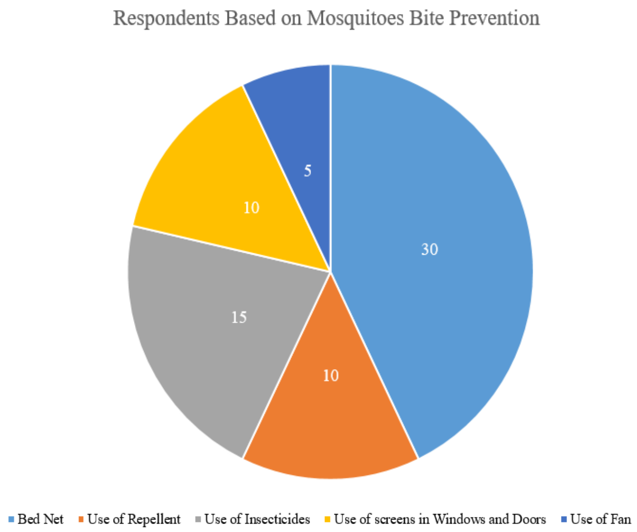

Figure 5. Respondents based on mosquitoes bite prevention

Aedes and *Anopheles* mosquitoes are the next most common species in Yakasai Region, behind *Culex* mosquitoes. According to the research, there are different mosquito populations, which can have different effects on the spread of disease. The prevalence of *Anopheles* and *A. gambiae* highlights the significance of malaria prevention methods, whereas the greater number of *Culex* mosquitoes indicates a focus on controlling this species. The distribution of genders among species emphasizes the necessity of focused interventions to control the feeding and breeding habits of female mosquitoes, which are principally in charge of spreading disease (Dahalan et al. 2019).

Table 2 also gives the number and percentage of fed and unfed mosquitoes that are present in Yakasai Area. The information distinguishes between mosquitoes that have been fed (fed) and unfed (unfed) blood meals. In Yakasai Area, fed and unfed mosquitoes were collected from the three sites; in site A, 38 mosquitoes were identified as fed under a microscope, 27 from site B, and 34 from site C, and there are 27 unfed mosquitoes from site A, 31 from site B, and 14 mosquitoes from site C, from the all species.

Table 2 shows that 99 mosquitoes, or 57.9% of the total mosquito population measured, were noted as fed. The aforementioned suggests that a significant proportion of mosquitoes in the Yakasai Region have exhibited host-seeking and feeding behaviors. Since fed female mosquitoes are the main carriers of mosquito-borne illnesses like dengue, Zika, and malaria, the high percentage of fed mosquitoes is alarming. The higher risk of disease transmission in the area indicated by this high proportion calls for the implementation of appropriate vector control and public health initiatives (Shaw et al. 2020). However, 72 mosquitoes, or 42.1% of the overall population, were found to be malnourished. Even while this percentage is lower than that of fed mosquitoes, it nevertheless indicates a sizable component of insects that have not yet consumed blood. Since these unfed mosquitoes are probably actively looking for victims, if they get infected after feeding, there may be a higher chance of bites and subsequent disease spread.

The 171 mosquitoes in Yakasai Area were surveyed. According to the data, a significant proportion of the mosquito population is feeding, which emphasizes the necessity of focused mosquito control efforts. Reducing the number of feeding mosquitoes through interventions including insecticide-treated nets, indoor residual spraying, and environmental management could greatly decrease the risk of disease transmission. Furthermore, it is critical to monitor and manage the population of fed mosquitoes to stop them from spreading disease after feeding (Jones et al. 2020). The results of this study are of paramount importance, as they highlight how crucial it is to implement comprehensive mosquito control measures in the Yakasai Region to maintain public health.

Table 3 and Figure 5 show the respondents' distribution according to their understanding of preventative measures against mosquito bites. The population's knowledge and protective measures against mosquito bites are reflected in the data, which is important in reducing diseases spread by mosquitoes. The table divides the respondents into two groups: those who know how to prevent mosquito bites and those who don't. The statistics showed that a sizable percentage of responders had information regarding preventing mosquito bites. This suggests that people are generally well-informed, which is encouraging for public health programs. In order to effectively avoid mosquito bites and the spread of disease, knowledgeable people are more likely to adopt preventative measures, including using insect repellent, donning protective clothes, and placing screens on windows and doors (Duval et al. 2023). However, it also shows that some of the respondents were ignorant of precautions against mosquito bites. This awareness gap is concerning because those who are unaware of preventive measures have a higher risk of contracting diseases linked to mosquito bites. This emphasizes the need for focused educational efforts and environmental outreach initiatives to increase public awareness and educate the public about practical methods to prevent mosquito bites. These initiatives might involve distributing educational materials, setting up workshops, and using media outlets to spread knowledge. The information also emphasizes the significance of ongoing instruction and reinforcement of preventative measures against mosquito bites. It is important to ensure that these techniques are applied continuously, even by qualified individuals. In order to encourage long-term behavioral change and assist the populace in implementing and upholding efficient preventative measures, public health officials and community leaders should collaborate (Monroe et al. 2021). The data shows that respondents have a relatively high level of knowledge regarding mosquito bite prevention, which is positive news for public health initiatives. However, addressing knowledge gaps in some populations is still important. As researchers, our role in implementing and improving educational programs and encouraging the regular use of preventative measures is crucial in reducing the prevalence of mosquito-borne diseases and improving public health in the region.

In Takur Adu'a and Yakasai locations, the analysis of the three tables offers a thorough summary of mosquito species distribution, feeding habits, and public awareness of mosquito bite avoidance. The great danger of mosquito-borne disease transmission can be seen from the large number of *Culex* mosquitoes in both areas and the high proportion of insects they feed on. Although there are still knowledge gaps, the substantial awareness of mosquito bite avoidance techniques among respondents is encouraging. This emphasizes the need for focused teaching programs to reduce the harm caused by the spread of mosquito populations. Moreover, ongoing public health education plays a crucial role in maintaining community welfare and reducing the prevalence of mosquito-borne diseases; effective vector control measures are also crucial (Suárez et al. 2020).

This study findings validate previous research that emphasizes the significant role of mosquito-borne diseases in global public health. Molecular identification methods, as outlined by Fall et al. (2021), are highly effective in detecting mosquito species that may be challenging to identify through morphological taxonomy. Fall et al. (2021) in his study collected 11,873 larvae and 4,843 adult *Culicine* mosquitoes from the sampling sites. Fourteen species from three genera—*Aedes, Culex,* and *Mansonia*—were identified, including *Anopheles theileri, Culex mimeticus, Culex pipiens,* and *A. gambiae*. These results are consistent with the findings of this work.

In conclusion, the findings of the Jigawa State study offer vital information about mosquito species identification, their function in the spread of malaria, and practical preventative measures. Numerous mosquito species are significantly present, especially *Culex* and *Anopheles*, which are known to carry diseases like malaria. The higher risk of disease transmission in Takur Adu'a and Yakasai is highlighted by the high percentage of fed mosquitoes, which highlights the active host-seeking and feeding activity of female mosquitoes. The *A. gambiae*, the main malaria vector, could be distinguished from other mosquito species using the morphological identification techniques that were used. In line with earlier studies, the study also proved the usefulness of molecular techniques for mosquito identification, highlighting the significance of precise species identification in public health initiatives. Although there are still information gaps, the general public's awareness of mosquito bite avoidance measures is typically high, highlighting the necessity for ongoing education programs. Efficient vector control tactics, like insecticide-treated nets, indoor residual spraying, and environmental management, are critical for lowering the number of mosquitoes carrying food and lowering the chance of disease spread. Conclusively, this research offers significant insights into the identification of mosquito species, their function in the transmission of malaria, and strategies for averting mosquito-borne illnesses. The results highlight the need for focused vector control strategies and ongoing public health education to shield Jigawa State communities from the serious health hazards associated with large mosquito populations.

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Diversity of butterfly species (Order: Lepidoptera) in riparian ecosystems of Bromo Tengger Semeru National Park, Indonesia

ANIDA REZA FAHLEFI[1,♥], KOESTRIADI NUGRA PRASETYA[2], NIRMALA FITRIA FIRDHAUSI[1], SAIFUL BAHRI[1,♥♥]

[1]Department of Biology, Faculty of Science and Technology, Universitas Islam Negeri Sunan Ampel Surabaya. Jl. Ir. Soekarno 682, Gunung Anyar, Surabaya 60294, East Java, Indonesia. Tel./fax.: +62-31-8410298, ♥email: yesaanidaa@gmail.com, ♥♥email: saifulsi@uinsa.ac.id
[2]Bromo Tengger Semeru National Park Area, Indonesia. Jl. Raden Intan No. 6, Polowijen, Malang 65125, East Java, Indonesia

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Abstract. *Fahlefi AR, Prasetya KN, Firdhausi NF, Bahri S. 2024. Diversity of butterfly species (Order: Lepidoptera) in riparian ecosystems of Bromo Tengger Semeru National Park, Indonesia. Intl J Bonorowo Wetlands 14: 66-73.* The existence of Bromo Tengger Semeru National (BTSN) Park, Indonesia is of utmost importance, as the function of the national park is to manage, convert, and preserve all flora and fauna and protect all ecosystems within the National Park Area. Forest fires have unfortunately occurred in Bromo Tengger Semeru National Park, leading to the destruction of several areas and causing habitat loss for various species, such as butterflies. This study, therefore, holds significant value as it aims to identify and analyze the diversity of butterfly species (Order: Lepidoptera) in BTSN Park Area, Indonesia, using the transect method combined with the Visual Encounter Survey method. The research location was divided into five locations: Ireng-ireng Area, Ranu Pani, Ranu Regulo, Ranu Darungan, and Trisula Riverbank; the measurement of factors supporting the presence of butterflies, such as temperature, humidity, and light intensity. Based on the research conducted, 46 butterfly species were found, with a total of 465 individuals from 5 families. Of the 46 species, 9 species were found to be endemic species and protected species. To determine the value of butterfly species diversity, it is calculated using the Shannon-Wiener diversity index. The results of the index analysis obtained from the five locations are: (Location 1) diversity index H'=3.32, (Location 2) diversity index H'=1.21, (Location 3) diversity index H'=1.39, (Location 4) diversity index H'=1.91, (Location 5) diversity index H'=2.55. These findings are crucial for understanding and conserving the biodiversity of this unique national park.

Keywords: Butterflies, endemic, forest fire, transect

INTRODUCTION

Species diversity is a characteristic of a community that indicates the level of diversity of the types of organisms present within it. Every organism in an ecosystem has a population that fluctuates over time and is never the same. Similarly, the ecosystem formed by populations and their physical environment continuously changes and evolves (Siregar et al. 2014). Species diversity can be marked by differences in color, size, shape, quantity, texture, appearance, and other characteristics (Ridhwan 2012). The diversity of species can also be seen through the similarities in traits among them. Recognizing living beings, especially animals, based on their characteristics. By observing morphological traits, habitat, reproduction methods, types of food, behavior, and several other observable features, one can gain a deeper understanding of species diversity (Peres et al. 2023).

Lepidoptera, with >150,000 species, are the second largest and most diverse. Lepidoptera are generally winged insects with layers of small scales. Butterflies belong to the Order Lepidoptera (Suhaimi et al. 2017). Butterflies are brilliantly colored and beautifully patterned organisms (Mayur et al. 2013). Butterflies are flying insects that have three parts: cephal, thorax, and abdomen (Rawat et al. 2023). Butterflies undergo complete metamorphosis (holometabolous), meaning they go through the stages of egg, caterpillar, pupa, and imago (Wellmann 2023). Butterflies play an important role in pollination (Martínez-Adriano et al. 2018). The relationship between flowering plants and flower-visiting insects is important for preserving terrestrial ecosystems and leads to different insect-plant and insect-herbivore interactions. Butterflies are considered the second pollinator after bees (Koneri et al. 2022). It was previously reported that butterflies are able to disperse in various habitats such as forests, gardens, grasslands, and metropolitan areas (Basri and Zakaria 2021). About 90% of butterfly species live in the tropics (Suwarno et al. 2018).

In Indonesia, it has been estimated that about 2500 species are found, while about 35% of them are endemic (Murwitaningsih and Dharma 2014). The diversity of butterfly species is different in each place and cannot be separated from the carrying capacity of its habitat. The presence of butterflies can be influenced by several factors, including host plants both as larval hosts and as nectar sources for imago; physical factors such as temperature, humidity, and light intensity are also important factors that limit the presence of butterflies in a place (Apriana et al. 2022). This is why not all places can be used as butterfly breeding grounds.

Bromo Tengger Semeru National (BTSN) Park, Indonesia is one of the conservation areas with abundant biodiversity, both from flora and fauna. The research on butterflies in BTSN Park is not the first of its kind. Research on butterfly diversity was conducted by Millah et al. (2020) on the diversity of butterflies (Lepidoptera: Rhopalocera) in the BTSN Park. This research was conducted at four observation points: Ranu Darungan, Ranu Pani, Ranu Regulo, and Ireng-ireng Area. The results of the research revealed that there are 41 species from 5 different families. The research shows that the Shannon-Wiener diversity index result is H'= 1.73.

Forest fires occur in BTSN Park; the destruction of several BTSN Park is the main cause of habitat loss for various species of animals. Changes often accompany forest fires and decreases in biodiversity. Organisms have beneficial interactions with local habitats. This interaction between organisms and habitats can be a reference for information related to how changes in natural habitats affect populations of organisms such as butterflies (Forister et al. 2019). The impact of the fires that occurred in BTSN Park can be the cause of changes in the existing ecosystem; therefore, it is important to conduct research to get the latest data on butterfly diversity in BTSN Park is very important. This study aims to determine the diversity of butterfly species (Order: Lepidoptera) in BTSN Park, Indonesia.

MATERIALS AND METHODS

Studi area

Data collection began in February and ended in April 2024 with three repetitions. Each month, one repetition was conducted at each research location to obtain valid data. Data collection was carried out during sunny conditions, with observation time from 07.00 WIB until 12.00 WIB. This observation was carried out in the Bromo Tengger Semeru National (BTSN) Park, Indonesia (Figure 1). The observation location in BTSN Park is divided into five locations: the Ireng-Ireng Area, Ranu Pani, Ranu Regulo, Ranu Darungan, and Trisula Riverbank (Table 1).

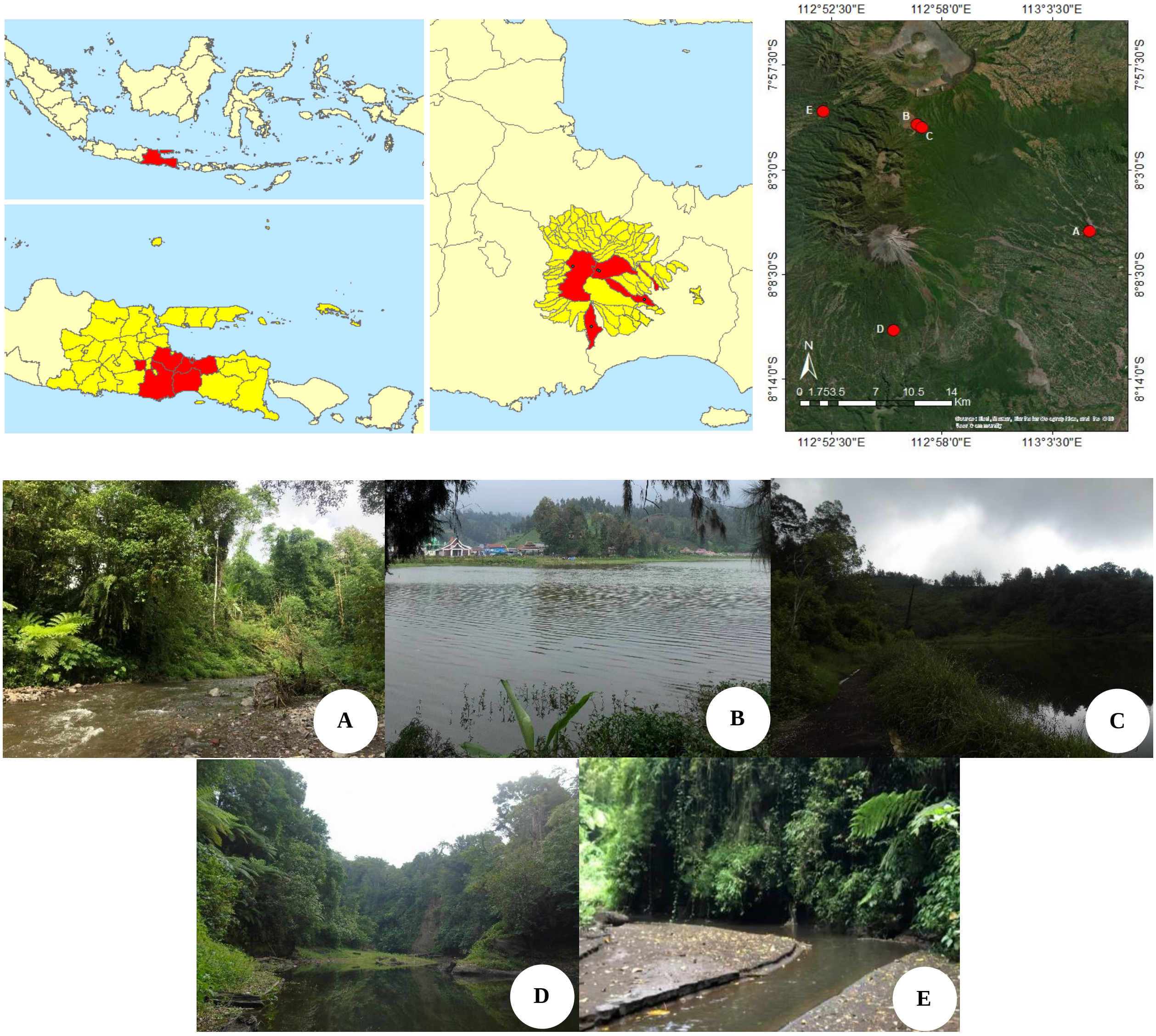

Figure 1. Research location of Bromo Tengger Semeru National Park, Indonesia. A. Ireng-ireng Area, B. Ranu Pani, C. Ranu Regulo, D. Ranu Darungan, E. Trisula Riverbank

Table 1. Description of location in Bromo Tengger Semeru National Park, East Java, Indonesia

Location	Description
L1 (Ireng-ireng Area)	The Ireng-ireng has an open canopy and a stream. This location has diverse vegetation and is located in the middle of the forest so there is no human activity.
L2 (Ranu Pani)	Ranu Pani has an open canopy, a non-flowing lake, and no dense vegetation. Humans often visit this location.
L3 (Ranu Regulo)	Ranu Regulo's canopy tends to be open, and there is a lake that does not flow. This location is covered by fog, making it difficult to make observations.
L4 (Ranu Darungan)	Ranu Darungan's canopy tends to be open, and there is a lake that does not flow. Diverse vegetation makes this location frequently visited.
L5 (Trisula Riverbank)	Trisula Riverbank has dense vegetation with a canopy that tends to be open, and a flowing water habitat type. This location does not detect human activity because it is located in the middle of the forest.

Data collection method

The observation method is done directly or the Visual Encounter Survey (VES) method (Lestari et al. 2018). Visual Encounter Survey is a method carried out by recording and counting the number of individuals of butterfly species encountered during active butterfly hours (Zulaikha and Bahri 2021). The transect method was combined with the VES method. Butterfly observation transects were also established along 10 meters of roadside paths. The transect route is divided into several observation points that provide information on the distribution of local butterflies (Priyono and Abdullah 2013).

After capturing the butterflies, identification was done with the help of an identification book (Rositawati 2016; Ilhamdi et al. 2018). This study was conducted in conjunction with measurements of abiotic factors, including temperature and humidity using a thermohygrometer; and light intensity using a lux meter. These factors were measured in the morning before starting the butterfly data collection. Research was also made on the type of vegetation and canopy surrounding the butterfly habitat.

Data analysis

The total individuals obtained were then calculated using the relative abundance formula to determine the percentage of species, then analyzed using Microsoft Excel software.

Diversity index

According to Koneri et al. (2020), to determine the value of butterfly species diversity, it is calculated using the Shannon-Wiener diversity index formula as follows:

$$H' = -\sum pi \; Ln \; pi$$

Where:
H′: Diversity index
Pi: Total ni/N
ni: Number of individuals of type i
N: Number of individuals of all type
Ln: Natural logarithm

Evenness index

$$E' = \frac{H'}{\ln S}$$

Where:
E: Evenness index
H': Diversity index
S: Number of species
Ln: Natural logarithm

Dominance index

$$D = \Sigma \, (ni/ N)^2$$

Where:
D: Dominance index
ni: Number of individuals of a species
N: Number of individuals of all species

Relative abundance

$$RA = \frac{ni}{N} \times 100\%$$

Where:
RA: Relative abundance
ni: Number of individuals of a species
N: Number of individuals of all species

RESULTS AND DISCUSSION

Based on observations at five stations spread across BTSN Park, 46 butterfly species were found with 465 individuals in total. The butterfly species are included in five families: Hesperiidae, Lycaenidae, Nymphalidae, Papilionidae, and Pieridae. Nymphalidae is the family with the highest number of species found in this observation, with a total of 24 species. The large proportion of this family is due to Nymphalidae having more than one host plant. This can fulfill its need for host plants even though the main host plant is not available. This condition causes Nymphalidae to be found quite large in the observation location (Priyono and Abdullah 2013). The Hesperiidae was the least-found family in this observation, with a total of 3 species (Table 2).

The abundance of butterfly species in the BTSN Park area varies greatly at each observation station, but there is a dominant species at the observation station, namely *Ypthima pandocus* with a relative abundance value of 7.31%. *Mooreana trichoneura*, *Athyma selenophora*, *Vanessa cardui*, and *Papilio arjuna* are species with the least relative abundance value of 0.22%. The *Y. pandocus* (Figure 2.D) is often found in diverse vegetation and streams. Mountain ecosystem conditions with high air humidity and low temperature with sunlight intensity so that this species is often found. This is supported by Sari et al. (2016), who stated the presence of Eupatorium odoratum plants, which are food plants in all habitat types, is one of the main reasons for the abundance of *Y. pandocus*. Of the 46 species, 9 species were found to be endemic species, namely *Cyrestis lutea* endemic to Java and Bali; *Mycalesis moorei* and *Delias aurantiaca*, endemic to Java; and *P. arjuna* (Figure 2.T), endemic to Indonesia. *Zizina otis*, *Junonia almana* (Figure 2.J), *V. cardui*, *Troides cuneifera*, and *Troides helena* (Figure 2.P) are classified as Least Concern (LC) species according to the IUCN (International Union for Conservation of Nature) Red List data.

Table 2. Observation data on butterflies in Bromo Tengger Semeru National Park, East Java, Indonesia

Species	**Location**					**Total**	**RA%**	**Conservation status**
	1	**2**	**3**	**4**	**5**			
Hesperiidae								
Mooreana trichoneura (C. Felder & R. Felder, 1860)	1	-	-	-	-	1	0.22	NE
Notocrypta paralysos (Wood-Mason & de Niceville, 1881)	8	-	-	-	4	12	2.58	NE
Potanthus trachala (Mabille, 1878)	8	-	-	-	3	11	2.37	NE
Lycaenidae								
Heliophorus epicles (Godart, 1823)	3	-	-	-	2	5	1.08	NE
Poritia erycinoides (Felder, 1865)	-	-	-	3	-	3	0.65	NE
Udara dilecta (Moore, 1879)	21	-	-	-	-	21	4.52	NE
Zizina otis (Fabricius, 1787)	23	-	-	-	5	28	6.02	LC
Nymphalidae								
Acraea issoria (Hübner, 1819)	-	7	2	-	-	9	1.94	NE
Athyma selenophora (Kollar, 1844)	1	-	-	-	-	1	0.22	NE
Cyrestis lutea (Zinken, 1831)	9	-	-	-	-	9	1.94	NE
Euploea mulciber (Cramer, 1777)	4	-	-	2	1	7	0.43	VU
Euthalia whiteheadi (Grose Smith, 1889)	2	-	-	-	-	2	0.43	NE
Faunis canens (Hübner, 1826)	2	-	-	-	-	2	0.43	NE
Hypolimnas bolina (Linnaeus, 1758)	2	-	-	1	-	3	0.65	NE
Ideopsis gaura (Horsfield 1829)	3	-	-	1	-	4	0.86	NE
Junonia almana (Linnaeus, 1758)	-	-	-	25	-	25	5.38	LC
Junonia atlites (Linnaeus, 1763)	-	-	-	28	-	28	6.02	NE
Junonia iphita (Cramer, 1779)	2	-	-	-	-	2	0.43	NE
Mycalesis moorei (C. Felder & R. Felder, 1867)	9	-	2	-	10	21	4.52	NE
Neptis hylas (Linnaeus, 1758)	13	-	-	1	3	17	3.66	NE
Neptis vikasi (Moore, 1899)	4	-	-	-	-	4	0.86	NE
Parantica aspasia (Fabricius, 1787)	4	-	-	3	-	7	1.51	NE
Symbrenthia hypselis (Godart, 1824)	14	-	-	-	1	15	3.23	NE
Symbrenthia lilaea (Hewitson, 1864)	8	-	-	-	1	9	1.94	NE
Tanaecia iapis (Godart, 1824)	7	-	-	-	-	7	1.51	NE
Tanaecia trigerta Moore, 1857	3	-	-	-	-	3	0.65	NE
Telchinia issoria (Fruhstorfer, 1914)	-	6	-	-	-	6	1.29	NE
Vagrans egista (Cramer, 1780)	2	-	-	-	-	2	0.43	NE
Vanessa cardui (Linnaeus, 1758)	-	-	-	-	1	1	0.22	LC
Ypthima nigricans Snellen	8	-	-	-	2	10	2.15	NE
Ypthima pandocus (Moore, 1857)	16	-	-	4	14	34	7.31	NE
Papilionidae								
Graphium antiphates (Cramer, 1775)	2	-	-	-	-	2	0.43	NE
Graphium doson (C. Felder & R. Felder, 1864)	-	-	-	2	-	2	0.43	NE
Graphium sarpedon (Linnaeus, 1758)	11	-	2	5	-	18	3.87	NE
Papilio arjuna (Horsfield, 1828)	-	1	-	-	-	1	0.22	NE
Papilio helenus (Linnaeus, 1758)	15	-	-	-	-	15	3.23	NE
Papilio memnon (Linnaeus, 1758)	12	-	-	2	1	15	3.23	NE
Papilio polytes (Linnaeus, 1758)	3	-	-	-	-	3	0.65	NE
Troides cuneifera (Oberthür, 1879)	8	-	-	-	-	8	1.72	LC
Troides helena (Linnaeus, 1758)	5	-	-	-	4	9	1.94	LC
Pieridae								
Appias olferna (Swinhoe, 1890)	6	-	-	-	4	10	2.15	NE
Cepora iudith (Fabricius, 1787)	5	-	-	-	-	5	1.08	NE
Delias aurantiaca (Doherty, 1891)	-	-	-	-	2	2	0.43	NE
Delias belisama (Cramer, 1779)	2	-	-	1	17	20	4.30	NE
Eurema blanda (Boisduval, 1836)	21	-	-	3	5	29	6.24	NE
Leptosia nina (Fabricius, 1793)	9	3	2	-	3	17	3.66	NE

Figure 2. A. *Symbrenthia lilaea*, B. *Notocrypta paralysos*, C. *Tanaecia iapis*, D. *Ypthyma pandocus*, E. *Ideopsis gaura*, F. *Euthalia whiteheadi*, G. *Hypolimnas bolina*, H. *Parantica Aspasia*, I. *Poritia erycinoides*, J. *Junonia almana*, K. *Junonia atlites*, L. *Neptis vikasi*, M. *Potanthus trachala*, N. *Eurema blanda*, O. *Heliophorus epicles*, P. *Troides helena*, Q. *Symbrenthia hipselis*, R. *Papilio helenus*, S. *Graphium sarpedon*, T. *Papilio arjuna*, U. *Euploea Mulciber*

The Ireng-Ireng Area, a location of significant importance in butterfly research, is where the highest number of butterfly species are found, with a diversity index value of H'=3.32 (Figure 3). The vegetation in this area makes the presence of butterflies abundant. The high diversity value is a result of the even distribution of individuals per species, indicating that all species in the community have approximately the same number of individuals. Station 1, with its abundant water sources for mineral purposes and a relatively open canopy with high light intensity compared to other stations (Table 3), supports a high diversity of butterfly species and a large number of butterflies that carry out activities optimally. The environmental support components, such as the availability of habitat, water, minerals, food, temperature, and humidity, play a crucial role in shaping the unique butterfly diversity of the Ireng-Ireng area, making it a valued area of study (Mas'ud et al. 2018).

Severns (2008) said that the butterfly population in a community is influenced by light intensity. Station 1 has the most species diversity because it has the highest light intensity than other stations (Table 3). This is supported by Nurjannah (2010), who said that the appropriate light intensity for butterfly development is 2,000-7,500 lux. Butterflies are animals with scaly wings (Lepidoptera) that are active during the day when light intensity is high. High sunlight intensity is necessary because butterflies utilize the sun's heat when flying. When the weather is dark or rainy, butterflies will take shelter behind leaves. Butterflies need light because butterflies are cold-blooded (poikilotherm) (Nuraini et al. 2020). Light will provide heat energy so as to increase body temperature, and metabolism becomes faster; in butterfly larvae, an increase in body temperature will accelerate the development of butterfly larvae (Rahayu and Basukriadi 2012).

At the Ranu Pani location, *P. arjuna* species was found absorbing minerals in the soil (Figure 2.T). The *P. arjuna* that is distributed in Sumatra and Java. This change is based on research conducted by Condamine et al. (2023), which suggested that *P. arjuna* is an independent species because it has undergone speciation. This species is now endemic to Indonesia. Ranu Pani is the research location that has the smallest diversity index value, H'=1.21. This is due to the temperature at this location being very low compared to other locations. The impact of temperature on butterfly activity, distribution, growth, and breeding cannot be overstated. Based on the measurement of environmental factors, it is found that temperature is inversely proportional to humidity (Table 3). This is in accordance with Febrita et al. (2014) that the high and low value of air humidity in an area is influenced by air temperature in the area, where temperature is inversely proportional to humidity. The higher the ambient temperature, the lower the humidity, and vice versa.

Ranu Regulo is a location surrounded by mist, the main cause of humidity. The vegetation found in this area is not varied. At the Ranu Regulo location, 4 species were found consisting of *Acraea issoria*, *M. moorei*, *Graphium sarpedon*, and *Leptosia nina*. Ranu Regulo has a diversity index value of H'=1.39. *A. issoria* species, with its unique habit of perching in bushes and slow flying ability, has a relative abundance value of 1.94%. The species *M. moorei* was found perching on its host plant. The genus *Mycalesis* generally uses Poaceae as its host plant (Rositawati 2016). *M. moorei is* endemic to Java. This species is classified as Not Evaluated in the IUCN Red List. Species *G. sarpedon* (Figure 2.S) has been found absorbing minerals from the soil and engaging in an activity known as puddling. The *L. nina* species, with its unique ability to fly low and slow, is often found resting in bushes (Rositawati 2016).

Ranu Darungan has dense vegetation and an open canopy, with 14 species and 81 individuals recorded. Ranu Darungan has a diversity index value of H'=1.91. *Junonia atlites* species dominated this location with a relative abundance value of 6.02%. The *J. atlites* species were found perched on the grass (Figure 2.K). The host plants of *J. atlites* include several, such as wild rice (*Oryza* sp.), *landep* (*Barleria* sp.), and *kunang* plants (*Strobilanthes* sp.) (Kurniawan and Samani 2023). Species *Graphium doson* is only found in the Ranu Darungan location, with a total of 2 individuals. The *G. doson* was found mating in a flying position. Its wings have a black base color with blue spots.

Trisula Riverbank is a location that has a diversity index value of H'=2.55. The *D. aurantiaca* was the only species found at Trisula Riverbank. During observation, this species was found flying with *Delias belisama*. This species is a type of butterfly that only exists in Indonesia on the island of Java (endemic Java). A rare and protected species was also found at this location, *T. helena* and *T. cuneifera*. This butterfly is often seen staying longer on plant flowers (Figure 2.P).

Table 3. Abiotic factor data

Location	Temperature (°C)	Humidity (%)	Light intensity (lux)
1 (Ireng-Ireng Area)	25-26	80	2854
2 (Ranu Pani)	11-12	94	1347
3 (Ranu Regulo)	19-20	92	1354
4 (Ranu Darungan)	25-26	90	1470
5 (Trisula Riverbank)	17-19	97	1132

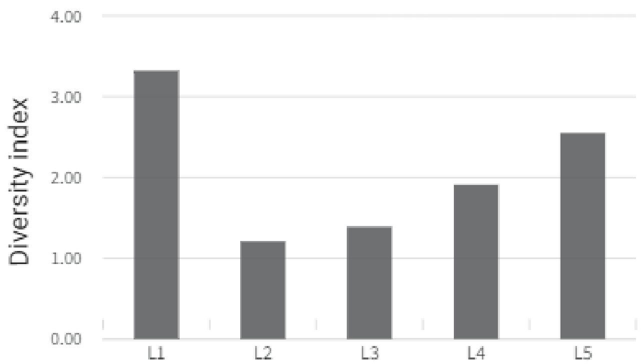

Figure 3. Diversity index

Troides helena can almost be found at all altitudes, especially at an altitude of 200-1,500 masl, in various types of forest habitats and is even sometimes seen in rural areas and city parks. Species *T. cuneifera* have a black body. The back wings are golden and have black spots. The female butterfly is dark brown and larger than the male butterfly. This bird has a high flying ability and is very fast. The species *T. helena* generally has a greater abundance of female *T. helena* butterflies compared to male butterflies. The flying activity of the *T. helena* species is very high (Harmonis 2021). Both of these species are classified under CITES (Convention on International Trade in Endangered Species of Wild Fauna and Flora) Appendix II, which means that their trade is prohibited.

Based on the results of the evenness index analysis on butterfly species in the BTSN area, there is a value of 0.92 at Location 1, Location 2 at 0.87, Location 3 at 1.00, Location 4 with a value of 0.72, and Location 5 at 0.87 (Figure 4). The average value of the butterfly evenness index at the observation site is 0.88. The evenness index in this area is classified in the high evenness category. Thus, the five locations have high evenness and stable communities. The dominance index is an index used to obtain data on butterfly species at the observation site that dominate in a community. The dominance index of butterfly species at the observation site can be seen in Figure 4. The results of the analysis of the dominance index of butterfly species at Location 1 are 0.04, at Location 2 it is 0.33; Location 3 it is 0.25, then Location 4 with a value of 0.23, and at Location 5 it is 0.11. The average butterfly dominance index value is 0.19. The butterfly dominance index value is low.

The dominance index obtained shows that from the abundance of individuals of butterfly species there is no very prominent dominance. This is in accordance with the statement of Purwowidodo (2015), that the dominance is not prominent because good habitat conditions at each station have the availability of living resources such as food, host plants, shelter, and breeding that are quite varied or heterogeneous for butterflies.

Figure 4. Evenness index and dominance index

The dominance index and evenness index formulas actually have a negative correlation. The dominance index is inversely proportional to the evenness index, meaning that if the dominance index is high, it indicates that a habitat has a low level of evenness of individuals; on the other hand, a low dominance index indicates a tendency for the abundance of individuals of butterfly species to be evenly distributed in a habitat. If the evenness is close to zero, it means that the evenness between species in the community is low. On the other hand, evenness close to one can mean that the evenness between species is relatively even or equal. This evenness index can be interpreted as the degree of evenness in the abundance of individuals between species (Nuraini et al. 2020).

The results of the research in BTSN Park revealed 46 species of butterflies with a total of 465 individuals from 5 families. Families that include Hesperiidae, Lycaenidae, Nymphalidae, Papilionidae, and Pieridae. Of the 46 species, there are endemic species such as *C. lutea*, endemic to Java and Bali; *M. moorei* and *D. aurantiaca*, endemic to Java; and *P. arjuna* endemic to Indonesia. The species *Z. otis*, *J. almana*, *V. cardui*, *T. cuneifera*, and *T. helena* are classified as low risk or Least Concern (LC) according to the IUCN Red List data. The species with the highest number of individuals is *Y. pandocus*, with a total of 34 individuals. The Diversity Index is classified as high, with a value of H'=3.47.

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The status of wetlands in seasonally flooded plains in eastern part of Lake Tana, Ethiopia

AKLILU AGIDIE[1,♥], AYALEW WONDIE[1], GETACHEW BENEBERU[2]
[1]College of Agriculture and Environmental Science, Department of Fisheries and Aquatic Science, Bahir Dar University. PO Box 79, Bahir Dar, Ethiopia. Tel.: +251-583-20-9653, ♥email: aklilubet@gmail.com
[2]College of Science, Department of Biology, Bahir Dar University. PO Box 79, Bahir Dar, Ethiopia

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Abstract. *Agidie A, Wondie A, Beneberu G. 2024. The status of wetlands in seasonally flooded plains in eastern part of Lake Tana, Ethiopia. Intl J Bonorowo Wetlands 14: 74-82.* Understanding the challenges and conditions of wetland ecosystems has become more critical. Wetland area coverage has gone through dramatic change, and multiple anthropogenic and natural processes threaten it ever so now. To this end, the study aims to evaluate the changes in wetland area coverage from 1990 to 2022, assess their current status based on multi-influencing factors, and analyze the drivers and pressures within a Driving-Pressure-State-Impact-Response (DPSIR) framework. Data were gathered through transect walks, focus group discussions, key informant interviews, and household surveys. The wetland area's land cover change was examined using the Landsat photos retrieved from Google Earth Engine. The result indicated that wetlands were lost at a higher rate, from 0.55 to 0.17%, while cultivated land expansion has substantially increased from 87.35 to 89.71%, respectively. The primary reason for the area's changing land cover was the population's explosive growth. Decreased production, the loss of biodiversity, and land scarcity were the main drivers. To encourage soil and water conservation, farmers must be trained in sustainable land management techniques, native vegetation plantation, and the restoration of wetlands and riverbanks through thoughtful land use planning.

Keywords: Agricultural expansion, climate change, human pressure, land conversion

INTRODUCTION

Wetlands are among the world's most valuable natural resources because they support a range of ecosystem services such as water and wetland products, flood mitigation, groundwater recharge, carbon sequestration, and nutrient removal (Heckwolf et al. 2021). Despite providing a wide variety of services, they are severely threatened ecosystems on our planet. Globally, 69-75% of the inland wetlands have been lost in the 20th century. The loss of inland wetlands has also been aggravated in the 21st century (Reis et al. 2017).

The loss of inland wetlands has been aggravated in the 21st century due to the influence of anthropogenic pressures and climate change. These ecosystems have dramatically changed due to agricultural expansion, urbanization, industrial development, and unsustainable water management. Wetlands have been especially impacted by these pressures because of their vital roles in flood control, water purification, and biodiversity conservation (Wondie 2018; Kingsford et al. 2021).

With global food demand increasing, fueled in part by population growth, many wetlands are drained and given over to agriculture. Such intensive farming associated with rice paddies and other water-consuming crops utilizes vast amounts of land and water resources, which destroys the wetlands. This trend is particularly pronounced in developing countries, where wetland areas are often seen as unused land for agricultural conversion (Jamal et al. 2023).

The functioning of wetland ecosystems, biodiversity, socioeconomic vulnerability, and environmental systems are all impacted by changes in land use (Anteneh et al. 2012). The Land use/land cover (LULC) change research in wetland ecosystems has received much less attention than the importance of these changes to ecosystem health and function. Since the 2020s, many studies have used elaborate remote sensing, GIS, and spatial modeling methods to track LULC variation and its impact on wetlands (Zhu et al. 2023).

Therefore, to perform wetland status assessments of land cover change challenges, various researchers are utilizing satellite remote sensing integrated with the DPSIR (Driving forces, Pressures, State, Impacts, and Responses) approach. For instance, satellite remote sensing can provide near-real-time information on land use changes, climate conditions, and ecosystem dynamics (Gedefaw et al. 2020) that may help researchers monitor environmental conditions over time. Meanwhile, the DPSIR framework is an organized approach to understanding relationships between human activities and environmental outcomes that facilitates a holistic study of cause-and-effect pathways (Obubu et al. 2022). These two approaches together allow researchers to adjoin the benefits of satellite data at a large spatial scale with qualitative DPSIR detail, leading to more reasonable policy recommendations and environmental management strategies (Carnohan et al. 2023).

Empirical studies have explored the factors contributing to wetland loss, with many identifying several key drivers. Among these, the conversion of wetlands into agricultural land due to population growth and increased demand for food products (Obubu et al. 2022; Zekarias and Gelaw 2023), infrastructure expansion and urbanization, overexploitation of biological resources, the spread of invasive species (Assefa et al. 2023), alterations to hydrological regimes for irrigation (Gedefaw et al. 2020), and climate change have been highlighted as major threats. Collectively, these factors have been recognized as significant contributors to the ongoing degradation and loss of natural wetlands (Plain et al. 2018; Mereta et al. 2020).

In Ethiopia, research over the past two decades has extensively examined changes in LULC, including their causes and impacts on hydrology and land degradation (Mereta 2013). However, many of these studies have either been conducted in watersheds without wetlands or have classified wetlands merely as water bodies (Guelmami et al. 2023). To accurately predict environmental changes and obtain reliable land use statistics across various administrative levels, effective monitoring of wetland ecological land use is essential (Tewabe and Fentahun 2020).

Limited comprehensive information exists on the dynamics of land use and land cover surrounding seasonally flooded wetland areas. Therefore, this study aims to assess the spatiotemporal changes in the basin's wetlands over the period from 1990 to 2022 and identify the key factors contributing to wetland degradation. By conducting an LULC analysis, this research will help bridge the knowledge gap, providing valuable insights into land-use trends that can inform strategies for wetland restoration and conservation.

MATERIALS AND METHODS

Description of the study area

Lake Tana sub-basin, with its rich wetland, is found in the upper Abay basin, which is the highland freshwater body in northwest Ethiopia (Figure 1). Rainfall is unimodal, with the highest portion occurring between June and September, with a total annual precipitation of 1100 and 1530 mm (Ndue et al. 2023). The Lake Tana Basin is home to a variety of biodiversity with pervasive flora and fauna, including fish, birds, and vegetation. It comprises more than thirty islands and has numerous seasonal and permanent wetlands. The lake provides different services to the community by supplying irrigation, hydroelectric power, transportation, agricultural services, and harvested goods (Heide 2012). The biomes are in the afro-tropical highland zone groups (Mereta 2013). The two main enormous rivers, Gumara and Rib, overrun and strengthen the permanent wetlands while producing a large number of seasonal ponds. Lake Tana sub-basin wetlands have deteriorated from time to time due to heavy human involvement and a recent invasion by water hyacinth (*Eichhornia crassipes*), affecting the overall ecological integrity of the system.

Procedures

Remote sensing data and preprocessing

Land cover maps of the study area were produced from Landsat 5 TM satellite imagery for 1990 and Sentinel-2 satellite imagery for the period 2017-2022. Landsat images were garnered through the United States Geological Survey (USGS) when Sentinel-2 data was extracted from ESRI (Guelmamni et al. 2023). ArcGIS 10.2.2 software was used for analysis, and map preparation. Sentinel-2 satellite platforms supply high-resolution images, which makes them ideal for time series land-cover classification.

To maintain the correct classification, we performed a long data capture process before carrying out the segmentation and visual collection of reference data based on observations from Google Earth time lapses. By using pure pixel values, this method was able to diagnose land cover types at Landsat (30 × 30 m) and Sentinel-2 (10 × 10 m) resolution criteria (Dang et al. 2022). Reference data were compiled independently for 1990 and 2022 across a total of 1,500 points (500 more specifically dedicated to land cover class stratification). The other 1,000 points were reserved for assessing the geographical accuracy of the maps derived from this Conducting this data collection to validate classifications is an essential step in ensuring the reliability of the land cover assessments. The accuracy of the classification was assessed using randomly selected reference sample points. Overall accuracies, kappa coefficients, user's and producer's accuracies measures were calculated based on (Chaaban et al. 2022).

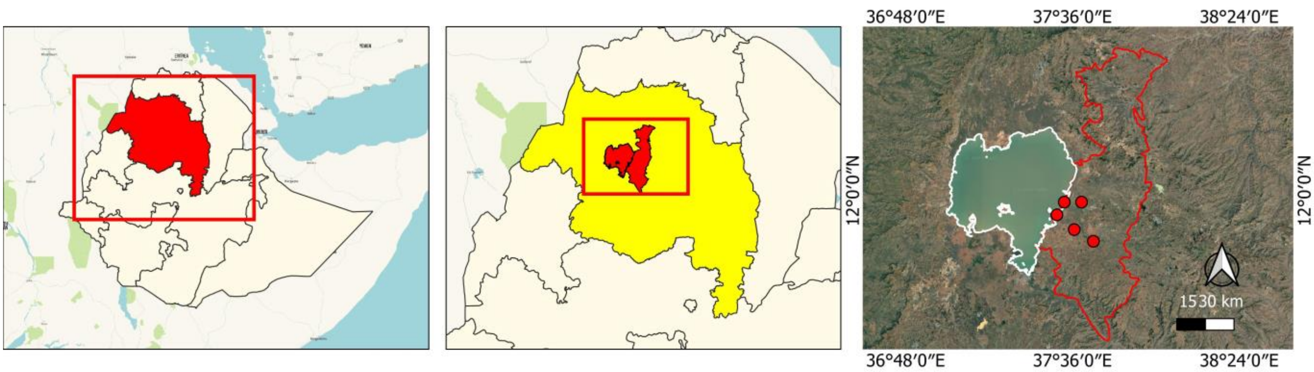

Figure 1. Map of Lake Tana sub-basin showing the study locations

Field data collection

In the study area, ground reference data were collected to validate each land cover type. Although there is no single accepted criteria for the minimum size of a sample, Karimi and Talebi (2023) suggest at least 50 samples per class, especially for regions smaller than 4,000 km^2 and having fewer than six classes. In order to attain a strong representation, samples for each of the six defined land cover categories (Assefa et al. 2021; Mulatu et al. 2024) (Table 1) were collected in at least 80 different locations. These cover types are wetland/flooded vegetation, water bodies, cultivated and grazing land, forest, settlement area, and bare/shrub land as described in (García-Álvarez et al. 2022).

Data analysis

Land cover classification

The land cover classifications for three years (1990, 2017, and 2022) were completed with supervised pixel-based classification and a maximum likelihood classifier (MLC). This technique was chosen because, under Karimi and Talebi (2023) (Gedefaw et al. 2020), it computes the statistical likelihood that a given pixel value corresponds to a specific land cover type using the regular distribution of a cloud of points and parameters. The reference data included spectral signatures for each type of land cover.

Land cover change analysis

ESRI ArcGIS 10.2.2 software was utilized to perform picture classification and image processing procedures. Calculations were made of the percentage changes for each type of land cover throughout time (Dixon et al. 2021). Gains and losses for particular classes, as well as overall and net changes in the research area, were evaluated. Furthermore, as per (Rahmawaty et al. 2022), annual change rates were computed for every kind of land cover category (Table 1).

Household survey and data analysis of DPSIR framework of land cover change

We conducted household surveys among landholder households to gain insight into the DPSIR of land cover change and to understand how the land cover situation has evolved. A two-stage sampling procedure was used to choose household respondents. A random selection of 150 household respondents was made, taking into account the total number of household respondents in each selected kebele. The sample size was calculated using the equation provided by Cochran (1977). Household respondents' perspectives on land cover dynamics were collected through a semi-structured questionnaire. Statistical tools were employed to investigate the records. Additionally, qualitative insights had been amassed from focus group discussions (FGDs) and interviews with key informants.

DPSIR frame in the identification of factors of land cover changes

The DPSIR framework was applied to apprehend the elements using land cover modifications, together with pressures and drivers, which might be critical for sustainable land control. International organizations have extensively applied the DPSIR framework (Bradley and Yee 2016).

This model helps to elucidate the interactions and interfaces that affect environmental conditions. Drivers refer to social and cultural forces that shift in response to demands for essential resources, while human actions that stress the environment can be considered drivers as well. These environmental driving forces create pressures, which include modifications in land cover. The 'State' denotes the modern-day composition of land use, which those stresses may also modify. The 'Impacts' refer to changes in land cover that affect human welfare, and 'Responses' are the actions taken in reaction to perceived land use changes. These responses can range from nearby remediation efforts to broader policy adjustments aiming to address stresses or enhance land use situations.

Changes in land cover have been diagnosed, quantified, and analyzed via classifying satellite photo time collection. The accuracy of the land cover classification supported a qualitative evaluation of the wishes, states, pressures, influences, and responses related to land cover changes within the have-a-look-at-the location.

Table 1. The land use/land cover (LULC) categories

Categories	Description
Wetland and flooded vegetation areas	Habitat comprised of marsh fields and meadows that are either seasonally or permanently inundated with water sustain hydrophytic plant life but are frequently subjected to human disruption. These habitats are vegetated wetlands, primarily of herbaceous plants and fodder grasses that develop in marshy areas along littoral areas of water bodies or massive structures.
Waterbody	Water bodies are lakes, rivers, springs, ponds, and open water located in the basin.
Cultivated and grazing lands	Land under cultivation is where annual crops, vegetables, and fruits are grown. Cattle are pastured on landscapes of grass and occasional trees called grazing lands.
Trees/Forest	The landscape comprises a mosaic of closed and open forests, shrublands, church forests (indigenous forest patches protected by Christian churches), urban trees, riverine forests, and *Eucalyptus* plantations.
Settlements	Built-up areas contain all buildings serving residential, commercial, and industrial purposes, as well as transport infrastructure like roads.
Bare/Shrubs	Since the terrain is mostly bare soil and exposed rocks in some areas, there are shrubs and isolated vegetation with small trees (almost half of the area), thorny bushes, and short shrub grasses.

Data from three acquisition years (1990, 2017, and 2022) provided valuable insights for assessing landscape conditions, land use changes, and potential management responses. The DPSIR model proves to be an effective tool for evaluating cause-and-effect relationships among the interacting elements of social, economic, and environmental systems.

RESULTS AND DISCUSSION

Land cover changes

Temporal analysis revealed that the extent and changes in land cover over the past three decades varied according to land cover type. The LULC (Land Use/Land Cover) maps for the eastern part of the Lake Tana sub-basin, spanning three reference years (1990, 2017, and 2022), are illustrated in Figure 2, and Tables 2 and 3.

In this study area, there has been a marked increase in cultivated land and settlements, while wetland and flooded vegetation areas have declined. These changes highlight the significant impact of land cover transformations on wetland ecology, as evidenced in Figures 2 and 3, and Table 3.

Between 1990 and 2017, cultivated land increased by 21,115.89 ha (5.48%), while wetland area decreased by -1,271.88 ha (-52.69%). The main cause of this change was the transformation of wetlands into pasture and agricultural land. While settlement areas increased by 11,892.13 ha (51.88%) between 2017 and 2022, wetlands and water bodies further decreased by -386.73 ha (-33.86%) and -6.93 ha, (-0.18%) respectively. As a result, between 1990 and 2022, the pace of wetland loss was -51.83 hectares per year, whereas the rate of expansion of cultivated land was 342.2 hectares per year. The rate of increase in settlement areas was 41.34 hectares per year (Table 3).

Accuracy of land cover maps

Table 4 presents the accuracy assessment for the supervised land cover classification, showing an overall accuracy of 87.1% for 1990, 86.3% for 2017, and 89% for 2022, respectively. The kappa coefficients are 0.83 for 1990, 0.83 for 2017, and 0.86 for 2022, respectively. These accuracy levels meet the required standards, making the land cover maps suitable for further analysis and change detection.

Table 2. Total land cover hectares and the percentage between 1990, 2017, and 2022

Land cover type	Area					
	1990		2017		2022	
	(ha)	%	(ha)	%	(ha)	%
Wetland and flooded veg.	2,414.08	0.55	1,142.20	0.26	755.46	0.17
Waterbody	2,007.04	0.45	3,891.10	0.88	3,884.17	0.88
Cultivated and grazing	385,623.50	87.35	406,739.38	92.01	396,573.97	89.71
Trees/Forest	8,160.42	1.85	7,177.61	1.62	6,047.90	1.37
Settlement	33,492.84	7.59	22,923.48	5.19	34,815.61	7.88
Bare/shrubs	9,793.59	2.22	207.45	0.05	3.25	0.001

Table 3. Land cover changes, net change, and rate of changes

Land cover type	Change (%)			Net change (ha)			Rate of change (ha/year)		
	1990-2017	2017-2022	1990-2022	1990-2017	2017-2022	1990-2022	1990-2017	2017-2022	1990-2022
Wetland and flooded veg.	-52.69	-33.86	-68.71	-1,271.88	-386.73	-1,658.61	-47.11	-77.35	-51.83
Waterbody	93.87	-0.18	93.53	1,884.06	-6.93	1,877.13	69.78	-1.39	58.66
Cultivated and grazing	5.48	-2.50	2.84	21,115.89	-10,165.41	10,950.48	4,485.77	-2,033.08	342.20
Trees/Forest	-12.04	-15.74	-25.89	-982.80	-1,129.71	-2,112.51	-36.40	-225.94	-66.02
Settlements	-31.56	51.88	3.95	-10,569.37	11,892.13	1,322.77	-4,095.16	2,378.43	41.34
Bare/shrubs	-97.88	-98.43	-99.97	-9,586.14	-204.20	-9,790.34	-355.04	-40.84	-305.95

Table 4. Accuracy assessment (in %) of land cover maps (1990, 2017 and 2022)

Land cover type	1990		2017		2022	
	User's accuracy calculation	Producer's accuracy	User's accuracy calculation	Producer's accuracy	User's accuracy calculation	Producer's accuracy
Wetland and flooded veg.	100	100	100	100	100	100
Waterbody	76.8	100	100	78.6	64.9	100
Cultivated and grazing	100	55.6	95.3	92.4	100	50.00
Trees/Forest	73.4	100	70.5	82.1	100	100
Settlement	100	86.4	100	94.1	100	100
Bare/shrubs	78.2	100	64.7	72.1	77.42	100
Overall accuracy	87.1		86.3		89	
Kappa statistics	0.83		0.83		0.86	

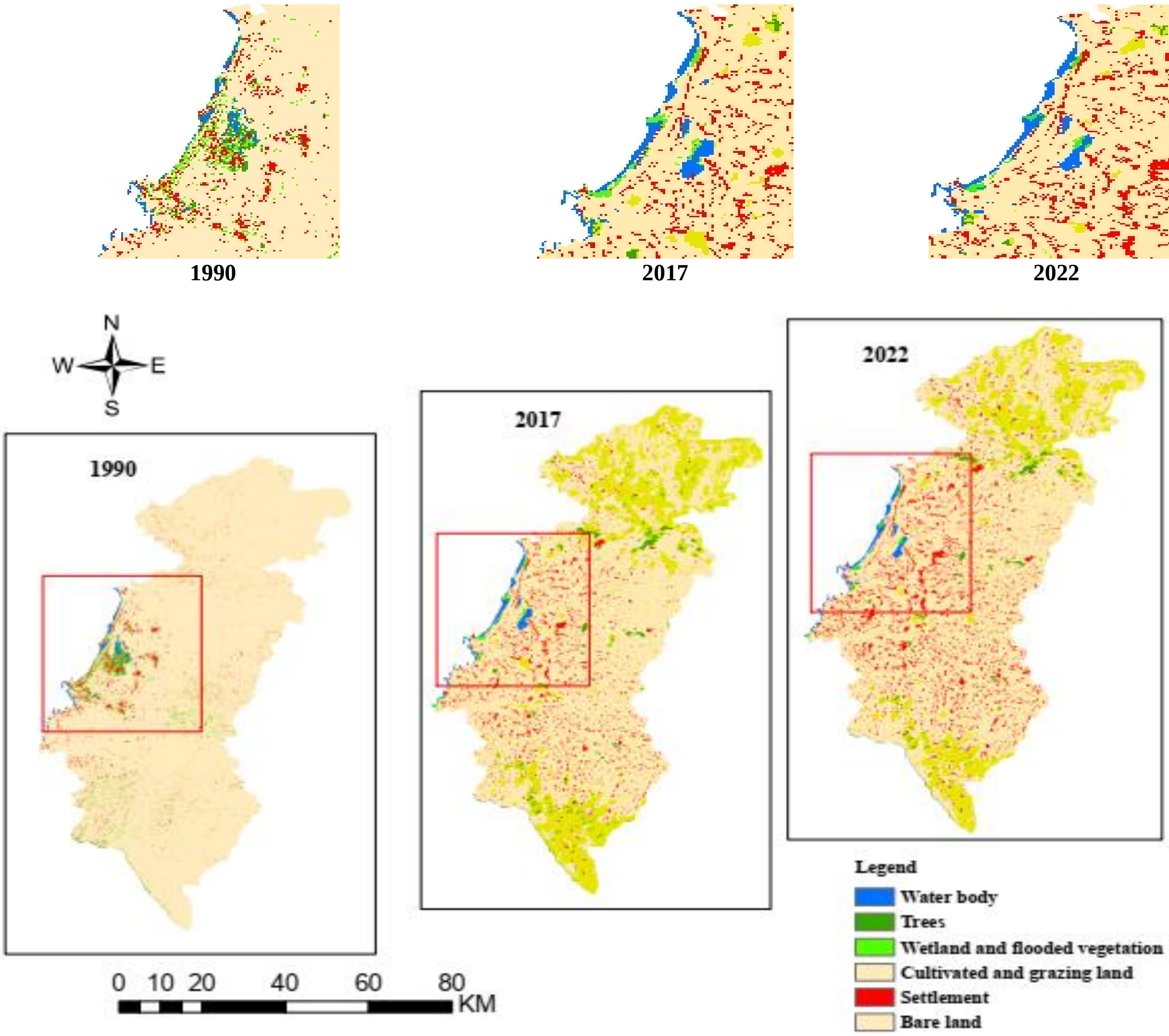

Figure 2. Land use land cover map of the study area from 1990 to 2022

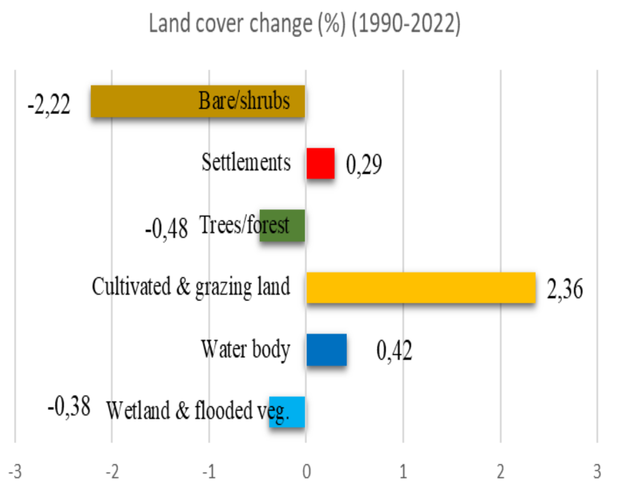

Figure 3. Land cover change of the study area over the study period

DPSIR indicators in relation to land cover change

Moreover, 81% of respondents observed a boom in cultivated land and settlements over the last 32 years. Meanwhile, 82% believed that vegetations, which includes shrubland recovery and tree planting, had additionally increased at some stage in this period. Additionally, 86% of participants noted a reduction in the area of bare land. These perceptions gathered through interviews were compared with the quantitative results from remote sensing-based land cover mapping (Figure 4).

Drivers for the change in land cover

Various factors drive land cover changes. In the research sites, the primary contributors were population growth (98.67%), a shortage of grazing land (98%), excessive land use (94.67%), reductions in farm size (70%), and climate change (66.67%) (Figure 5). The increasing populace intensifies the call for land, leading to tremendous land cover modifications through the years due to rapid human growth.

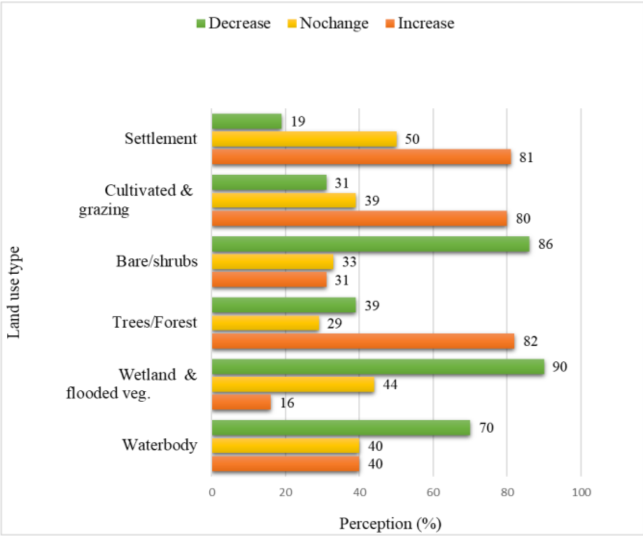

Figure 4. Respondent's perception of LULC changes for (1990-2022) (N=150)

Pressures resulting from changing land cover

According to household respondents, the pressures imposed by land use alternate highlight the need for stakeholder cooperation. These include a high demand for wetland products (98%), agricultural land demand (94.67%), seasonal flooding (78%), overgrazing (90%), competition on common land (60%), and stakeholder interests (50%) (Figure 5). The increasing population is adding more pressure on the already limited wetland resources that are now available, particularly on agricultural land, fuel wood, building supplies, and harvesting goods. The basin is under pressure because of the demand for land resources.

States of the land as a result of the change in land cover

The respondents in the study area reported the following current states (conditions) as a result of changing land cover: Change in agricultural system from animal husbandry (livestock) to cropping (94.67%); wetland degradation (85.3%), biodiversity loss (83.33%), increased land fragmentation (76.67%), poor water quality (68%), soil erosion (63.33%), rainfall variability (53.33%), loss of soil fertility (50.67%) (Figure 4). These findings underscore the importance of the audience's expertise in solving these issues. Respondents stated that the current state (condition) of land in the study area was caused by changes in land cover, including shifts from raising animals to raising crops, rainfall variability, loss of soil fertility, and soil erosion.

Impacts of land cover change

According to household respondents and as illustrated in Figure 5, the primary effects observed in the subbasin included decreased land productivity (91.33%), increased resource consumption (96%), population changes (98%), loss of biodiversity (83.33%), and reduced soil quality (74.67%). The effects of land cover change have worsened habitat loss and biodiversity fragmentation, making biological populations more liable to speculative risks due to human-brought changes in land cover.

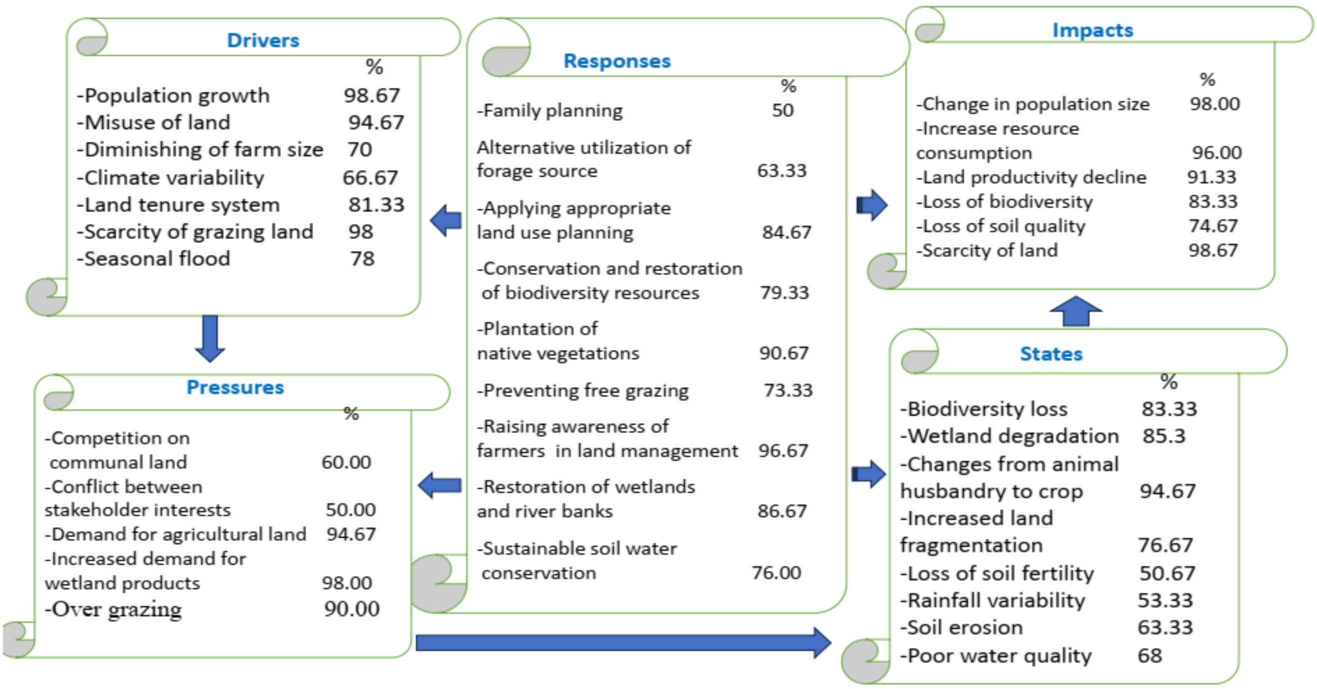

Figure 5. DPSIR framework model of land use land cover (LULC) change and respondents' reaction (%) (N=150)

Respondent's inspiration concerning the impact of the land cover change

Respondents recommended several measures to cope with land cover modifications, such as raising farmers' awareness about land management (96.67%), planting native plants (90.67%), restoring wetlands and riverbanks (86.67%), imposing effective land use-making plans (84.67%), keeping and restoring biodiversity sources (79.33%), practicing sustainable soil and water conservation (76%), preventing free grazing (73.33%), utilizing alternative forage sources (63.33%), and promoting family planning (50%) (Figure 5).

Wetlands status and major threats

Field surveys and satellite imagery have been applied to identify diverse land uses and covers, including wetlands, flooded vegetation flora, water bodies, agriculture, grazing lands, settlements, bare lands, and trees. These land covers show temporal modifications of spatial distribution.

The local community notes a decrease in wetland areas over time, which agrees with the results of satellite image investigations. They observed that the wetland had been shrinking periodically, with water being pumped and tired for irrigation to sustain crop and vegetable production in the dry season.

Wetland ecosystems face massive environmental pressures, consisting of in-depth agricultural activities, urban and rural settlement expansion, the introduction of invasive species, pollutants, climate change, human disturbances, and excessive pesticide use. These threats undermine wetland biodiversity and the critical environmental offerings, which include water purification, flood control, and carbon sequestration. Additionally, *Eucalyptus* tree plantations had been identified as extensive participants in wetland loss in some areas.

Since the 1990s, rice production in the floodplain has increased, leading to encroachment of wetland areas through agriculture and pasturing. The practice of recession agriculture, particularly within the lake's coastal region at some point in the dry season, appreciably exacerbates environmental destruction.

Discussions

Land cover changes

Various factors contribute to the dynamic changes in wetland and aquatic-framed land cover. Seasonal flooding and silt deposition from the Gumara and Rib rivers have brought about the buildup of sediment on wetlands, riverbanks, and the lake. Additionally, non-stop agricultural activities at higher and mid-altitudes inside the surrounding regions have notably degraded the wetland's pristine nature.

Land cover change maps indicate a steady decline in wetlands coverage while cultivated land and settlements have elevated. As highlighted by various researchers (Obubu et al. 2022; Zekarias and Gelaw 2023), it's clear that human activities, along with agriculture and settlement expansion and climate variability, have periodically contributed to the shrinking of wetland areas.

Between 1990 and 2022, cultivated land and settlements increased by 10,950.48 ha (0.03%) and 1,322.77 ha (0.04%), respectively. This expansion primarily resulted from the conversion of wetlands and flood-prone vegetation into farmland and residential areas. According to (Assefa et al. 2021), wetlands and water bodies have steadily diminished over the years while cultivated land has expanded significantly. Similarly, Gebresllassie et al. (2014) observed the widespread conversion of wetlands into agricultural land in various regions.

The accuracy assessment of supervised land cover classification revealed an overall accuracy of 87.1% for 1990, 86.3% for 2017, and 89% for 2022, with corresponding Kappa coefficients of 0.83, 0.83, and 0.86, respectively. These accuracy levels met the required standards for further analysis and change detection. Consistent with these findings, various studies (Gedefaw et al. 2020) confirmed that overall classification accuracy typically ranges from 86.3 to 93.4%, with Kappa coefficients between 0.83 and 0.91.

DPSIR indicators for changes in land cover

Household respondents identified several key pressures linked to changing land cover: a rise in demand for wetland resources (98%), heightened demand for agricultural land (94.67%), and overgrazing (90%). Gebresllassie et al. (2014), Mabidi et al. (2017), Obubu et al. (2022), Guelmami et al. (2023), and Karimi and Talebi (2023) have further highlighted those urgent problems.

Land use changes have exacerbated soil fertility depletion, habitat loss, and biodiversity decline, escalating the vulnerability of biological populations to potential dangers. Similar studies by Heide (2012), Mereta et al. (2020), and Zekarias and Gelaw (2023) have all confirmed these alarming findings.

According to participants, the most crucial steps to mitigate these challenges include investing in land resources, implementing effective land-use planning, and raising community awareness of sustainable land management, conservation, and rehabilitation practices. Comparable recommendations were also suggested by Plain et al. (2018) and Rahmawaty et al. (2022).

Wetlands health and major threats

The local community's observations align with the satellite image analysis, confirming the degradation of wetlands. Respondents are well aware of the diminishing wetlands, often noting that their size fluctuates. During the dry season, the local society employs irrigation by pumping and draining marsh water for crop and vegetable production. This emphasizes how the society role is very important to the preservation of wetlands (Worku 2014; Dixon et al. 2021; Fetene and Teshager 2020).

Various factors and significant environmental risks have impacted the wetland quality of Ethiopia's Lake Tana sub-basin, particularly affecting biodiversity. Wetland ecosystems face numerous threats that disrupt their ecological functions. Several studies (Worku 2014; Elo et al. 2018; Zhang et al. 2023) have identified human activities as the primary pressure on these ecosystems. Watershed degradation and *Eucalyptus* plantations are significant contributors to wetland loss in certain areas, a finding consistent with research by (Mereta 2013; Plain et al. 2018).

The major wetlands, Shesher, Welela, Sendye, Dilmo, Bebeks, littoral zones, and seasonal ponds within the basin have been declining due to natural pressures and human activities. Over time, most wetlands in the basin have experienced a decline in-depth, along with the littoral zones of lakes and riverbanks. For instance, the Shesher wetlands, which had a maximum intensity of 1.75 meters in 2012 (Anteneh et al. 2012), have now decreased to a depth of just 0.5 to 1 meter. Similarly, the Welala Wetland, although deeper than different areas with a recorded depth of 2.5 meters at some point in the wet season (Anteneh et al. 2012), has its depth decreased at most to just one meter. This decline is attributed to climate variability, human interference, and erratic rainfall patterns.

Intensive agricultural practices, such as rice farming, the spread of invasive alien species, soil and water pollution, recurrent climate variability, human disturbances, and the great use of fertilizers and insecticides in wetland crop fields, have caused massive biodiversity loss and the degradation of surroundings services in wetland ecosystems. Studies by Gebresllassie et al. (2014), Winn and Thu (2021), and Zekarias and Gelaw (2023) highlight that invasive species and climate alternates are key drivers of land degradation and wetland ecology loss.

Implementing effective land use mitigation strategies is vital to addressing those demanding situations. These encompass supervising and observing natural reserves, promoting natural revegetation, securing and safeguarding wetlands, and raising public focus through outreach initiatives. Restoring the degraded wetland ecosystems around Lake Tana is important. Implementing sustainable land use practices will mitigate degradation, even as promoting the regeneration of local vegetation and controlling invasive species will help to restore the wetlands' health.

Limitations of the study

Despite presenting treasured insights, this study has some limitations. One of the primary demanding situations turned into appropriately categorizing water bodies, wetlands, and flooded vegetations, in particular while working with 30-meter Landsat imagery, which lacked the readability needed for unique land cover identification. Differentiating wetlands from water bodies, flooded vegetations, grazing land, and newly cultivated regions proved specifically hard. Additionally, distinguishing forests from recently planted trees and restored vegetation posed further demanding situations in satellite photograph classification. These limitations may also have caused both overestimations and underestimations of certain values. Furthermore, the low resolution of the far-flung sensing pictures hindered accurate class (Karimi and Talebi 2023).

In conclusion, over the period from 1990 to 2022, the expansion of cultivated land and settlements significantly reduced wetlands and flooded vegetation. The DPSIR model was used to assess the condition of the wetland ecosystem. Scientific research and local perspectives have confirmed the changes in land use and land cover change within the basin. The net land use changes have impacted ecosystem services associated with wetlands and other land covers, driven largely by population growth and demand for agricultural land. Major drivers are the conversion of natural habitats into agricultural land as well as over-harvesting activities in wetlands that both reduce habitat availability and biodiversity levels and degrade soil quality. Overgrazing of edaphic factors, their dry season wetland drainage, and alterations in hydrology sedimentation augment the challenges. These problems are compounded when local farmers drain wetland water to both increase arable land and facilitate crop irrigation. Another major threat involves the construction of a large irrigation dam on the Ribb River, which will block waters from entering the wetlands and its connection to nearby Lake Tana, which is crucial for wetland sustainability within this part of the floodplain. The degraded and overgrazed forage of the particular landscape also indicates planting native vegetation to help improve grazing fields surrounding wetlands like *Phalaris paradoxa*. We also need to replant *Papyrus* and *Typha* around wetlands, lakes, and riverbanks. Mitigation of further degradation can be achieved by the restoration of degraded wetland ecosystems surrounding Lake Tana and sustainable land use practices; enhancing the wetlands biodiversity through restoration of native vegetation and control of invasive species. Directly planting native plants and other forms of active restoration is one way to speed up these natural processes. Similarly, the monitoring and management of water resources during dry seasons will ensure that the wetlands continue to perform their hydrological functions. Engaging and raising awareness in the community is essential for long-term success. One way to address this issue is to promote local involvement in conservation efforts and raise awareness among communities about the value of wetlands. These will be further complemented by public outreach programs aligned with and incorporated into proposals for government policies and conservation incentives.

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Diversity of gastropods (Animalia: Mollusca) in the upper Bengawan Solo River, Central Java, Indonesia: Native versus alien species

ANGGI DWIKI REZA[1], ABEL SURYA MAHENDRA[1], AISYAH AIDA RIADI[1], ANISA EKA PUTRI ARYANTO[1], HERLINA NOOR AGUSTIN[1], ARU DEWANGGA[1], MUHAMMAD INDRAWAN[1], MUH. SULAIMAN DADIONO[2], AHMAD DWI SETYAWAN[1,3,♥]

[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Sebelas Maret University. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-663375, ♥email: volatileoils@gmail.com

[2]Department of Aquaculture, Faculty of Fisheries and Marine Science, Universitas Jenderal Soedirman. Jl. Dr. Soeparno, North Purwokerto, Banyumas 53122, Central Java, Indonesia

[3]Biodiversity Research Group, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

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Abstract. *Reza AD, Mahendra AS, Riadi AA, Aryanto AEP, Agustin HN, Dewangga A, Indrawan M, Dadiono MS, Setyawan AD. 2024. Diversity of gastropods (Animalia: Mollusca) in the upper Bengawan Solo River, Central Java, Indonesia: Native versus alien species. Intl J Bonorowo Wetlands 14: 83-95.* Bengawan Solo River in Java Island, Indonesia, is important habitat for aquatic organisms, one of which is gastropods. However, there is indication of the presence of invasive alien gastropods in this river, which might pose threat to native species. This study aimed to identify the diversity of gastropod species in the upper Bengawan Solo River, Central Java, Indonesia and assess the presence of invasive species measured. Data collection was conducted in December 2023 at five stations representing varying habitat conditions. Data was collected using the transect plot method and analyzed by calculating the Shannon-Wiener index, Simpson's dominance index and density. The invasive status of species was determined based on literature studies. The study revealed 23 gastropod species from 9 families. There were 16 invasive species found, including *Tarebia granifera*, *Sulcospira testudinaria, Faunus ater, Achatina immaculata, Pomacea canaliculata*, *Sermyla riquetii*, *Limicolaria flammea*, *Littorina littorea*, *Perpolita hammonis, Viviparus glacialis, Viviparus viviparus*, *Viviparus intertextus*, *Semisulcospira libertina*, *Brotia costula*, *Zebrina detrita,* and *Melanoides tuberculata*. There were 7 native species found, namely *Pila scutata, Pila ampullacea, Filopaludina javanica, Stenomelania punctata, Stenomelania denisoniensis*, *Cipangopaludina chinensis* and *Acavus phoenix*. The level of diversity of gastropod species in the upper Bengawan Solo River was in the medium category while the dominance index was low, indicating that there was no dominant gastropod in the upper Bengawan Solo River. Some invasive gastropod species had high density compared to other species, implying a threat to the native ones. This finding warrants attention since the dominance of invasive alien species can affect the ecological system balance and lead to the loss of native species.

Keywords: Diversity, dominance, gastropods, invasive, upper Bengawan Solo River

INTRODUCTION

Bengawan Solo River is the longest river system in Java Island, Indonesia, which administratively crosses two provinces: Central Java and East Java with a drainage area of 16,000 km^2 (Utomo et al. 2017). It plays important role in various aspects of human livelihoods such as fisheries, agriculture, industry, tourism, and other domestic interests (Mudjib and Lasminto 2013; Firmansyah et al. 2020). The upstream area of the Bengawan Solo River covers several districts in Central Java Province including Wonogiri, Sukoharjo, Surakarta, Karanganyar, and Sragen. The upstream area of Bengawan Solo River is important in maintaining biodiversity, yet it has undergone many changes compared to other rivers in Indonesia such as the construction of reservoirs, canals (*sodetan*), and dams (Darmawan et al. 2018). In particular, these changes affect the diversity and abundance of aquatic organisms formerly occurring in the upper Bengawan Solo River, including gastropods or snail groups (Aida et al. 2022).

Gastropods are an invertebrate group that belongs to the phylum Mollusca. They have soft bodies, use the abdomen for moving, and generally have shells. Gastropods generally have a threaded single shell and eyes, and are equipped with tentacles. They play a crucial role as bioindicators, which can indicate pollution in aquatic ecosystems. In unpolluted waters with low water discharge, gastropods are evenly distributed with great abundance. Conversely, in polluted waters, few gastropod species tend to dominate a habitat (Nurlina and Harahap 2023). Substrates and elements of contaminants affect the composition and diversity of gastropods (Ferisandi et al. 2018).

According to Wahyuningsih and Umam (2022), species distribution is determined by two factors, namely the availability of resources and the presence of barriers or obstacles. Gastropods have a wide range of habitat distribution. They can be found in various water ecosystems, ranging from flowing waters such as rivers to stagnant waters such as lakes, swamps, and reservoirs (Fernanda 2021). Gastropods are also found in various substrates; some are attached to river banks and plants and live in mud, rocks, gravel, and sand (Purnama et al. 2022a). Nonetheless, the existence of gastropods is strongly influenced by food availability and tidal conditions (Uribe et al. 2016).

Gastropods are widely used by local communities as a food source (Sundalian et al. 2022). However, native gastropod species are slowly being degraded by the presence of invasive alien species. These invasive gastropod species tend to compete, dominate and usually attack native species, posing a significant threat to the ecosystem equilibrium (David et al. 2017). In addition, invasive species can reproduce quickly without copulating with the opposite sex; thus, spreading invasive species can dominate water ecosystem and threaten biodiversity. Invasive alien species are also the direct cause of biodiversity loss in the world, through the homogenization process.

There are several studies in the topics of biodiversity in the upper Bengawan Solo River, including Hasan et al. (2023); Haqqi et al. (2024); and Pramono et al. (2024). Nonetheless, there is no analysis which focuses on the presence of gastropods in this area and the potential threat of invasive gastropod species. Given these scientific gaps, this study aims to identify the diversity of gastropod species and their potential invasiveness in the upper Bengawan Solo River. The results of this study is expected to provide insights into the diversity and dominance of gastropod species, distinguish between native and invasive species and identify environmental factors influencing their distribution in the upper Bengawan Solo River.

MATERIALS AND METHODS

Study period and area

The research was conducted on December 2023 in the upper Bengawan Solo River, Central Java Province, Indonesia (Table 1; Figures 1 and 2). Data was collected at five stations representing varying habitat conditions. Station 1 was located in Wonogiri District (Pokoh, Wonogiri, and Giritirto, Wonogiri) with muddy environmental conditions, and there were many cultivated plants on the river banks, such as cassava. Station 2 was located in Sukoharjo District (Colo Dam, Nguter, Sukoharjo, and Bacem Bridge, Grogol, Sukoharjo) with muddy and rocky environmental conditions, many aquatic plants and artificial infrastructure in the form of dams and embankments. Station 3 was located in Surakarta City (Jurug Bridge, Jebres, Surakarta and Kampung Sewu, Jebres, Surakarta) with muddy bank conditions and riverbanks were in the form of grassy floodplains with many aquatic plants. Station 4 was located in Karanganyar District (Ring Road Bridge, Dalon, Sroyo, Jaten, Karanganyar, and Ngabeyan, Kebakkramat, Karanganyar) with muddy conditions and covered with plants on the riverbanks. Station 5 was located in Sragen District (Sidokerto, Plupuh, Sragen and Pringanom, Masaran, Sragen), where conditions were muddy and the riverbanks were overgrown with plants.

Table 1. Geographical coordinates of study location in the upper Bengawan Solo River, Central Java Province, Indonesia

Station	District/city	Location	Coordinates
1A	Wonogiri	Outlet of Gajah Mungkur Reservoir, Karang Talun, Pokoh Kidul	7°49'59.42"S and 110°55'34.78"E
1B		Outlet of Gajah Mungkur Reservoir, Sukorejo, Giritirto	7°49'32.23"S and 110°55'33.61"E
2A	Sukoharjo	Colo Dam, Dusun III, Pengkol, Nguter	7°45'3.82"S and 110°53'58.02"E
2B		Bacem Bridge, Dusun II, Telukan, Grogol	7°36'48.71"S and 110°49'11.61"E
3A	Surakarta	Jurug Bridge, Pucangsawit, Jebres	7°33'59.62"S and 110°51'39.87"E
3B		Demangan Baru Sluice, Kampung Sewu, Jebres	7°34'36.59"S and 110°50'41.16"E
4A	Karanganyar	Ring Road Bridge, Dalon, Sroyo, Jaten	7°32'45.60"S and 110°52'19.46"E
4B		Near pig farm, Kanten, Sroyo, Jaten	7°31'27.19"S and 110°52'28.79"E
5A	Sragen	Masaran Bridge, Dusun I, Sidokerto, Plupuh	7°29'22.20"S and 110°53'35.31"E
5B		Sari Bridge, Dungus, Karanganyar, Plupuh	7°26'47.54"S and 110°54'56.20"E

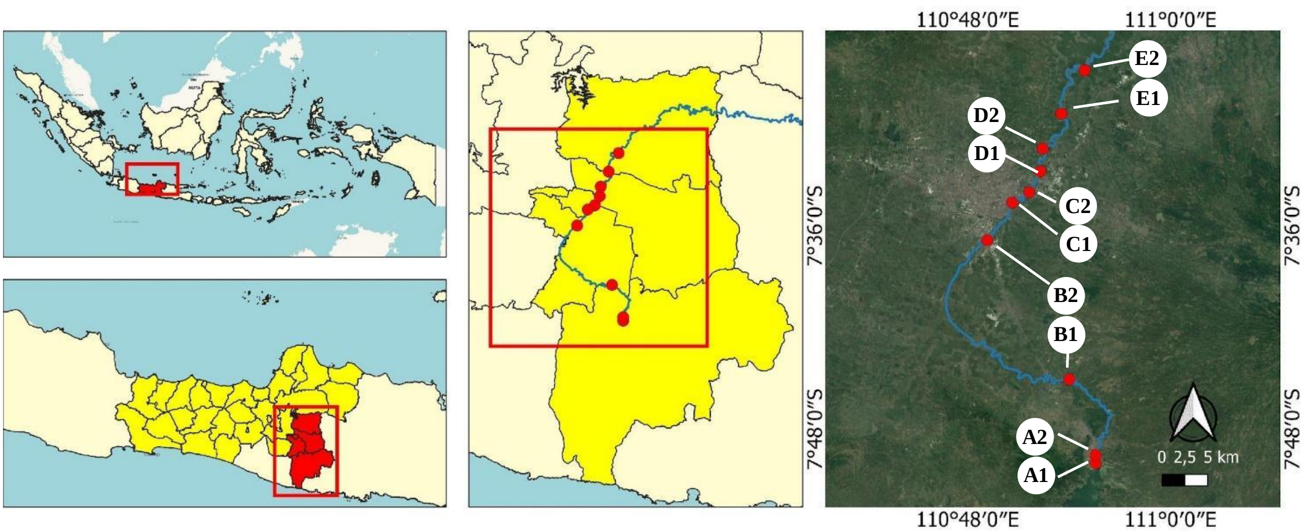

Figure 1. Map of study location in the upper Bengawan Solo River, Central Java Province, Indonesia. See Table 1 for more details

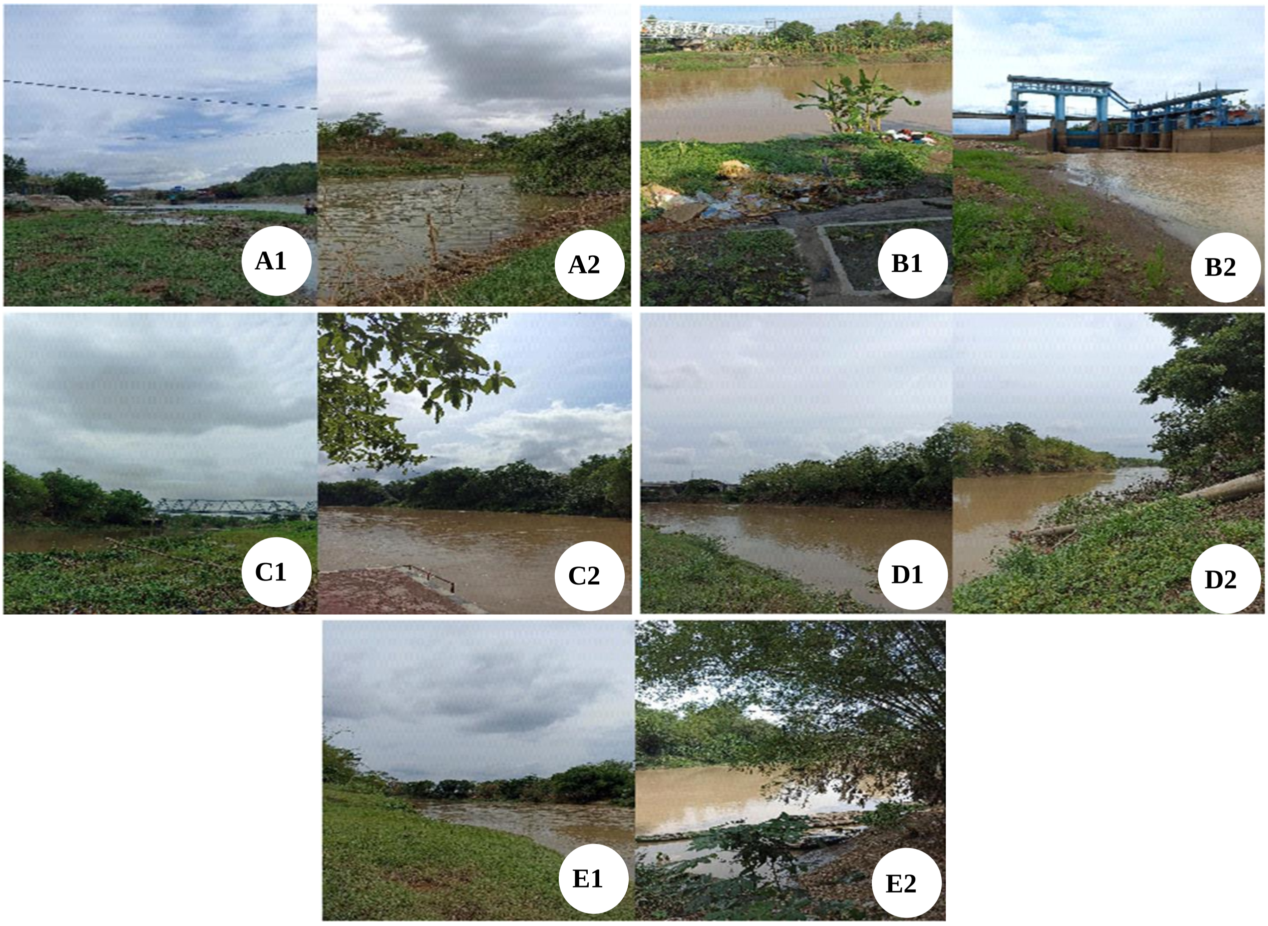

Figure 2. Condition of study location in upper Bengawan Solo River, Central Java Province, Indonesia. A. Station 1: Wonogiri; B. Station 2: Sukoharjo; C. Station 3: Surakarta; D. Station 4: Karanganyar; E. Station 5: Sragen. See Table 1 for more details.

Gastropod sample collection and identification

Sampling was carried out using a purposive sampling method with transect plots based on the conditions on the riverbank (Wahyuningsih and Umam 2022). Each sampling station consisted of two 70-meter transects along the river flow, with 2 × 2 m plots placed at a distance of 5 m between each plot (Hartati et al. 2022). Samples of living gastropods were collected and preserved with 70% alcohol, and gastropod shells were collected and then put into plastic bags for further identification. The identification process was carried out by focusing on the morphological characteristics of the gastropod samples, including shell shape, color, and pattern. After the species identification, the samples were documented using a digital camera. The determination of invasive and native gastropod species was carried out by referring to various references including Veeravechsukij et al. (2018); Wei et al. (2018); Maldonado and Martín (2019); Arias et al. (2020); David et al. (2020); Qin et al. (2020); Envin et al. (2020); Kalcheva et al. (2020); Marwoto et al. (2020); Rodrigo and Manamendra-Arachchi (2020); Sawada et al. (2020); Sánchez et al. (2021); Willan and Kessner (2021); Edgar et al. (2022); Gusna GM et al. (2022); Gurumayum (2023); Ouedraogo et al. (2023); Wang et al. (2023).

Data analysis

Gastropod samples that have been collected and identified were then analyzed. Data analysis of the number of species and individuals of each species collected was carried out using the Shannon-Wiener index (H') to determine the diversity of gastropods, Simpson's dominance index (C) to determine the gastropod dominance level, and density index (Di) to determine the gastropod density. The value of each index calculation is as follows:

The Diversity Index was calculated using the Shannon-Wiener formula (Krebs 1989) as follow:

$$H' = \sum_{i=1}^{s} [(ni/N)\ X\ ln\ (ni/N)]$$

Where: H': Diversity index; ni: Number of individuals of the i-th species; N: Total number of individuals

Shannon-Wiener diversity index is divided into 3 categories, namely:

H'<1: Low diversity; 1<H'≤ 3: Medium diversity; H'>3: High diversity

The Simpson's dominance index was calculated referring to Odum (1949) using the formula:

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

Where: C: Dominance index; ni: Number of individuals of the i-th species; N: Total number of individuals

The dominance index was classified into two:
$0<C\leq 0.5$: No species dominates; $0.5<C<1$: There is a dominating species

The gastropod density was calculated using the formula (Krebs 1989) as follow:

$$Di = \frac{ni}{A}$$

Where: Di: Density of individuals of the i-th species; ni: Number of individuals of the i-th species; A: Area of the sampling plot (m^2)

The data were then analyzed descriptively. The potential threats of invasive species were analyzed and described based on literature studies.

RESULTS AND DISCUSSION

Gastropods diversity

In total, there were 23 gastropod species belonging to 9 families in the upper Bengawan Solo River obtained from station 1 Wonogiri (9 species), station 2 Sukoharjo (9 species), station 3 Surakarta (10 species), station 4 Karanganyar (5 species), and station 5 Sragen (12 species). Thiaridae is the family with the largest number of species (7), followed by Viviparidae (5 species) and Ampullariidae with 3 species. Other families were represented by one species, including Littorinidae, Achatinidae, Pachychilidae, Achavida, Enidae and Gastrodontidae.

Gastropod species found at station 1 (Wonogiri) were *Tarebia granifera* (Lamarck, 1816), *Pomacea canaliculata* (Lamarck, 1822), *Melanoides tuberculata* (O.F.Müller, 1774), *Filopaludina javanica*, *Sermyla riquetii* (Grateloup, 1840), *Sulcospira testudinaria* Busch, 1842, *Stenomelania denisoniensis* (Brot, 1877), *Semisulcospira libertina* (A.Gould, 1859), and *Viviparus intertextus*. At station 2 (Sukoharjo), various species of gastropod were found, namely *T. granifera*, *S. testudinaria*, *S. libertina*, *P. canaliculata*, *Brotia (Brotia) costula* (Rafinesque, 1833), *Stenomelania punctata* (Lamarck, 1822), *F. javanica*, *Pila ampullacea*, and *M. tuberculata*. At station 3 (Surakarta) the gastropod species included *Pila scutata* (Mousson, 1848), *P. canaliculata*, *Faunus ater* (Linnaeus, 1758), *Limicolaria flammea* (O.F.Müller, 1774), *S. testudinaria*, *F. javanica*, *Achatina immaculata*, *Acavus phoenix* (L.Pfeiffer, 1854), *Perpolita hammonis* (Strøm, 1765), and *T. granifera*. At station 4 (Karanganyar), there were *T. granifera*, *P. canaliculata*, *S. libertina*, *A. immaculata*, and *M. tuberculata*. At station 5 (Sragen), gastropod found were *Viviparus viviparus* (Linnaeus, 1758), *P. canaliculata*, *T. granifera*, *Littorina littorea* (Linnaeus, 1758), *Viviparus glacialis* (S.V.Wood, 1872), *F. javanica*, *P. ampullacea*, *S. testudinaria*, *Cipangopaludina chinensis* (J.E.Gray, 1833), *A. immaculata*, *M. tuberculata*, and *Zebrina detrita* (O.F.Müller, 1774). Some gastropods are presented in Figure 3.

Table 2 shows that not all types of gastropod species can be found at all stations. This is similar to the research of Siswansyah and Kuntjoro (2023) that not all species of gastropods can live at a wide range of habitat because the water and substrate conditions are not suitable for their growth and survival. Nonetheless, *T. granifera* and *P. canaliculata* were found in all stations and easily adapt to the water quality of Wonogiri, Sukoharjo, Surakarta, Karanganyar, and Sragen.

The habitat of *T. granifera* is in lotic waters; it belongs to a form of fauna that lives attached to various types of substrates and is often found on the banks of river waters (Veeravechsukij et al. 2018). In addition to living in natural places, *T. granifera* can be found in man-made water bodies such as reservoirs or water irrigation channels (Majdi et al. 2022). According to research by Albarrán-Mélzer et al. (2020), the species can live between 20 and 38°C. *Tarebia granifera* can adapt to high turbidity and polluted water, so it's widely distributed. It can also be passively carried by river currents, water birds, etc. (Salwiyah et al. 2022). *Tarebia granifera* is considered as invasive alien species, its presence is often used as bioindicators of water pollution (Yakovenko et al. 2018).

Pomacea canaliculata, or gold snail species, can be easily found in various places, such as rice fields, rivers, lakes, and reservoirs (Noorshilawati et al. 2020). In its development at the age of 6 months, it can lay up to approximately 1000 eggs (Harahap et al. 2020). *P. canaliculata* is included in omnivores, which can eat dead animals, and in the food chain and it is included as predator (Kannan et al. 2020). The suitable temperature to adapt to its habitat is 23-32°C (Bae et al. 2021).

Filopaludina javanica, often known as *tutut*, is commonly consumed by human. It is a species that can adapt and survive in river waters with a temperature of 23-32°C, and even with heavy metals presence, such as Cu, Cr, Fe, Mn, Pb, and Zn (Arfiati et al. 2021). The average size of *F. javanica* shell height is between 15 to 35 mm, shell width is 12 to 25 mm and thickness is between 0.13-1 mm (Priawandiputra et al. 2020). *Sermyla riquetii* has similarities with *T. granifera*, which can survive at 20-38°C, and the shell structure is rough and wavy, only half of the shell color is white mixed with brownish (Lentge-Maaß et al. 2021). It is also included as invasive alien species (Wei et al. 2018).

Sulcospira testudinaria has a dark black or black mixed with a brownish color and has a different shell from the *M. tuberculata*. *Sulcospira testudinaria* has a blunt shell at the top and can live at 25-32°C (Arumsari and Adharini 2021). According to Nugroho et al. (2023), *S. testudinaria* has benefits in its shell because there is a potential source of calcium precursors; the shell is rich in calcium carbonate ($CaCO_3$), which can be thermally decomposed into calcium oxide (CaO) through calcination (Mujiono et al. 2019).

Table 2. Presence of invasive and native gastropod species in the Upper Bengawan Solo River, Central Java, Indonesia

Family	**Species name**	**Station**					**Substrate**	**Natural distribution**	**Invasive v.s. native**
		1	**2**	**3**	**4**	**5**			
Thiaridae	*Tarebia granifera* (Lamarck, 1816)	●	●	●	●	●	Mud	Southeast Asia	Invasive (Veeravechsukij et al. 2018)
Ampullariidae	*Pomacea canaliculata* (Lamarck, 1822)	●	●	●	●	●	Lithophytic, plants	South America	Invasive (Qin et al. 2020).
Thiaridae	*Semisulcospira libertina* (A. Gould, 1859)	●	●		●		Lithophytic, mud	Japan	Invasive (Sawada et al. 2020)
Thiaridae	*Melanoides tuberculata* (O.F. Muller, 1774)	●	●		●	●	Lithophytic, mud	Africa	Invasive (Ouedraogo et al. 2023)
Viviparidae	*Filopaludina javanica* (Busch, 1844)	●	●	●		●	Mud	Indonesia, Thailand	Native (Maldonado and Martín 2019)
Thiaridae	*Sulcospira testudinaria* (Busch, 1842)	●	●	●		●	Lithophytic	Indonesia	Native (Hertika et al. 2023)
Thiaridae	*Stenomelania punctata* (Lamarck, 1822)		●				Plants, mud	Indonesia	Native (Willan and Kessner 2021)
Thiaridae	*Stenomelania denisoniensis* (Brot, 1877)	●					Lithophytic	Indonesia	Native (Willan and Kessner 2021)
Viviparidae	*Viviparus intertextus* (Say, 1829)	●					Lithophytic	Latin America	Invasive (Arias et al. 2020)
Thiaridae	*Sermyla riquetii* (Grateloup, 1840)	●					Lithophytic, plants	Thailand	Invasive (Wei et al. 2018)
Ampullariidae	*Pila scutata* (Mousson, 1848)			●			Lithophytic, plants	Indonesia, Myanmar, Thailand	Native (Marwoto et al. 2020)
Ampullariidae	*Pila ampullacea* (Linnaeus, 1758)		●			●	Lithophytic, mud	Indonesia, Singapore	Native (Marwoto et al. 2020)
Pachychilidae	*Faunus ater* (Linnaeus, 1758)			●			Lithophytic	Philippines	Invasive (Gusna et al. 2022)
Achatinidae	*Limicolaria flammea* (O.F. Muller 1774)			●			Plants, lithophytic	West Africa	Invasive (Envin et al. 2020)
Achatinidae	*Achatina immaculata* (Lamarck, 1822)			●	●	●	Plants, lithophytic	Africa	Invasive (Wang et al. 2023)
Achavida	*Acavus phoenix* (L. Pfeiffer, 1854)			●			Plants, lithophytic	Sri Lanka	Invasive (Rodrigo and Manamendra-Arachchi 2020)
Gastrodontidae	*Perpolita hammonis* (Strom, 1765)			●			Plants, lithophytic	North America	Invasive (Sánchez et al. 2021)
Viviparidae	*Viviparus viviparus* (Linnaeus, 1758)					●	Plants, lithophytic	East Russia	Invasive (David et al. 2020)
Viviparidae	*Cipangopaludina chinensis* (J.E.Gray, 1833)					●	Plants, lithophytic	Indonesia, China	Native (Edgar et al. 2022)
Littorinidae	*Littorina littorea* (Linnaeus, 1758)					●	Mud	Russia	Invasive (Moisez et al. 2020)
Viviparidae	*Viviparus glacialis* (S.V. Wood, 1872)					●	Plants	United Kingdom	Invasive (David et al. 2020)
Enidae	*Zebrina detrita* (O.F. Muller, 1774)					●	Lithophytic, mud	European	Invasive (Kalcheva et al. 2020)
Pachychilidae	*Brotia costula* (Rafinesque, 1833)		●				Lithophytic	Southeast Asia	Invasive (Gurumayum 2023)

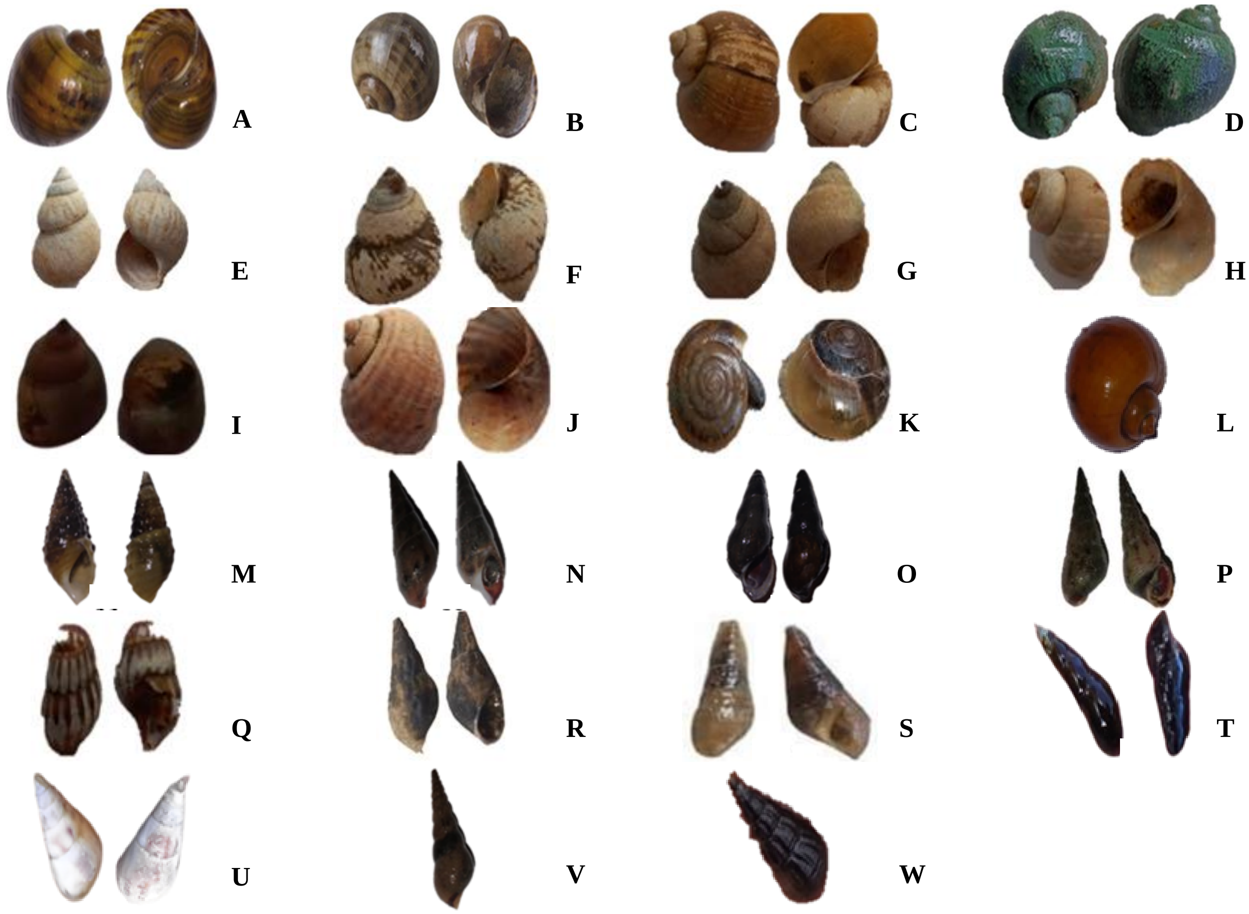

Figure 3. Various species of gastropods found in the upper Bengawan Solo River, Central Java, Indonesia: A. *Pomacea canaliculata*, B. *Viviparus intertextus*, C. *Pila ampullacea*, D. *Acavus phoenix*, E. *Viviparus glacialis*, F. *Achatina immaculata*, G. *Filopaludina javanica*, H. *Cipangopaludina chinensis*, I. *Viviparus viviparus*, J. *Littorina littorea*, K. *Perpolita hammonis*, L. *Pila scutata*, M. *Tarebia granifera*, N. *Faunus ater*, O. *Sulcospira testudinaria*, P. *Melanoides tuberculata*, Q. *Zebrina detrita*, R. *Sermyla riquetii*, S. *Semisulcospira libertina*, T. *Stenomelania denisoniensis*, U. *Limicolaria flammea*, V. *Stenomelania punctata*, W. *Brotia costula*

Stenomelania denisoniensis and *S. punctata* can survive at 20-38°C (Negus et al. 2021); it is often found in dense or sandy mud. However, based on their distribution, *Stenomelania* gastropods are distributed by sea from India to East Asia Island (Apiraksena et al. 2020). Different with *T. granifera*, this species is native species (Negus et al. 2021). *Semisulcospira libertina* has similarities with other species, such as *S. denisoniensis*. The shell structure is rough-patterned, small, brownish, mixed with greenish and black, and does not have a sharp shell on top. This species can live at 20-38°C in freshwater like rivers. Regarding benefits, the industrial sector often uses it to determine water pollution (Sano et al. 2022).

Melanoides tuberculata of Thiaridae family and *B. costula* of Pachychilidae family, can survive at 20-38°C (Nguyen et al. 2021). *Melanoides tuberculata* and *B. costula* are similar in size, which is long like a trumpet and green in color mixed with brown and black; but their structure is different. *Melanoides tuberculata* has a smooth shell and *B. costula* has a rough shell. Its benefits are often used as a source of animal protein (Oktavia et al. 2022). *Achatina immaculata* and *L. flammea* have similarities but differ in the shells' color. The color of *A. immaculata* is brownish mixed with green, and *L. flammea* has a black, brownish color mixed with white. Both species live in aquatic habitats with lithophytic substrates and plants. On the other hand, it is often found on riverbanks with humid environmental conditions and cold temperatures around 20-38°C, like other gastropods (Ehigie et al. 2020; Bohatá and Patoka 2023). The main benefit of *A. immaculata* and *L. flammea* is to provide additional nutrients for catfish farming (Mainisa 2019).

Acavus phoenix can live in water and on land (Salvador 2022). Its color is brownish mixed with white, and it has a similar shell to *V. intertextus*. The species is invasive but does not negatively affect other species. *Viviparus viviparus* and *V. glacialis* are snails living in freshwater waters and can survive with other species of gastropods from 20 to 38°C (Aini et al. 2020). Both species belong to the Viviparidae family of lithophytic substrates or plants. There are such differences, i.e. *V. viviparus* is brownish and blackish, while *V. glacialis* is white. Based on their habitat, they are included in the aquatic category (Preece et al. 2020). *Cipangopaludina chinensis* has a bright brownish shell color when exposed to sunlight; the species is often found on riverbanks with lithophytic substrates or plants to find food and lay eggs (Kingsbury et al. 2020). The shell of this species are often used for accessories (Sundalian et al. 2022). *Faunus ater* has a trumpet-like shell shape with a brownish color and live under the temperature of 20-38°C (Kurniawati et al. 2023). *Faunus ater* existence is rare, the species is only found in many sandy, rocky, and muddy places (Dewi et al. 2022).

Pila ampullacea has a flat but pointed shell shape with brown and blackish colors (Ng et al. 2020). It has positive properties, such as protein, calcium, etc., so the surrounding community often uses it for consumption to increase the immune system (Puspitasari et al. 2022). *Pila scutata* has the same color as *P. ampullacea*, but the structure of the shell tip is pointed. The species is native and does not cause harm to other species (Ng et al. 2020). *Pila scutata* is used as a bioindicator of water pollution (Prasetia et al. 2022). *Z. detrita* is a species with a small shell size, a blunt tip, and a brownish caramel color. The species' habitat is in the substrate of plants or mud. The temperature for survival are 20-38°C (Kalcheva et al. 2020). It can be used as accessories for bracelets, necklaces, etc. (Sundalian et al. 2022). *P. hammonis* is very difficult to find on the Bengawan Solo riverbanks because they likes lithophytic substrates in hard holes, such as concrete, on the banks of the river in humid conditions. The species live in the temperature of 20-38°C and they are often used to add nutrients to fish food (Makarchuk et al. 2020).

Invasive species of gastropods

As presented in Table 2, there were several gastropod species found in the upper Bengawan Solo River considered as invasive, including *T. granifera*, *S. testudinaria*, *F. ater*, *A. immaculata*, *P. canaliculata*, *S. riquetii*, *L. flammea*, *L. littorea*, *P. hammonis*, *V. glacialis*, *V. viviparus*, *V. intertextus*, *S. libertina*, *B. costula*, *Z. detrita*, and *M. tuberculata*. Some invasive species poses threat to native species, but some others are not (Kirk et al. 2020). The invasive gastropods originated from Southeast Asia, Japan, the American Continent, the European Continent, Middle East Asia, and the United Kingdom. Native gastropods are similar to those in other countries, including *S. testudinaria, F. javanica, S. punctata, S. denisoniensis, Perpolita harmonis, L. littorea, P. scutata, P. ampullacea*, and *C. chinensis* (Veeravechsukij et al. 2018; Sawada et al. 2020; Lailiyah et al. 2021; Nguyen et al. 2021; Gusna et al. 2022).

The spread of invasive alien species can harm native species when living in their new habitat due to competition for food (Veeravechsukij et al. 2018; Nguyen et al. 2021; Gusna et al. 2022), causing an imbalance in the ecosystem and affecting the numbers and types of benthic community structures (Raiba et al. 2022). *P. hammonis* is included as invasive species and prefers to live on plant stems (Sánchez et al. 2021). According to Yin et al. (2022), alien gastropods can produce eggs if they can adapt to their new habitat that supports their living, such as water quality, temperature, humidity, and turbidity. *T. granifera* and *F. ater* are invasive species originated from Africa and the Philippines and have some distribution in the Pacific Islands (Gusna et al. 2022). *T. granifera* and *S. testudinaria* easily reproduce by producing many eggs to be carried by ships or birds when looking a food, but *T. granifera* will more easily dominate in its new habitat (Yakovenko et al. 2018; Lentge-Maaß et al. 2021). *F. ater* differs from the other two species because it is difficult to adapt, and produced very few eggs (Dewi et al. 2022). *T. granifera* are dangerous because they on omnivorous species (Komatsu and Saeki 2022) which might act as the highest predators at trophic level (Aryzegovina et al. 2022), indirectly endangering other native species.

Pomacea canaliculata is considered as invasive (Qin et al. 2020). *Pomacea canaliculata* originated from South America, and was brought to Indonesia due to its benefits as a bioindicator (Qin et al. 2020). This species is considered invasive and can easily produce eggs, even though not as many as *T. granifera*; although, *P. canaliculata* is very difficult to find at some stations. *Semisulcospira* is a species native to Central Asia and is found in southern China and Japan and is considered as invasive although it do not harm other native species because it is a food source for fish (Sawada et al. 2020). This species can easily be found in 22.5°C waters with abundant foodstuffs such as plankton, detritus, and chemoautotrophic bacteria (Morita et al. 2024).

Melanoides tuberculata is an invasive which is easily found in various places where habitat conditions have a lot of algae resources (Ouedraogo et al. 2023). *Sulcospira testudinaria* is easy to find because it can produce many eggs, and the species easily adapts to the new environment (Du and Yang 2019). According to Wahyuningsih and Umam (2022), gastropod species can easily adapt because they tolerate polluted waters. *V. intertextus* is an invasive species (Arias et al. 2020) originated from the Asian continent and then moved to the American continent through sea transportation, humans, etc. (David et al. 2020). Some efforts that can be made against invasive alien species are mechanical, chemical, and biological controls (Syafei and Sudinno 2018). Therefore, if treatment efforts are not made and it indirectly enters Asia, this species can potentially endanger other native gastropods.

While there were several alien invasive species, there were native species of gastropods found in the upper Bengawan Solo River including *P. scutata*, *P. ampullacea*, *S. testudinaria*, *F. javanica*, *S. punctata*, *S. denisoniensis*, *C. chinensis* and *A. phoenix*. Research by Edgar et al. (2022) stated that *C. chinensis* is native species under the Viviparidae mollusca. *F. javanica* is a native gastropod with a small number that is difficult to find (Maldonado and Martín 2019). *Pila scutata* and *P. ampullacea* are native (Marwoto et al. 2020) which can produce hundreds of eggs laid in groups, stored above the water surface in moist soil, and protected by plant litters (Suartini and Sudatri 2021). *S. denisoniensis* and *S. punctata* are not considered harmful or invasive species (Willan and Kessner 2021). However, *S. punctata* was originally similar to invasive alien species such as *M. tuberculata* (Isnaingsih et al. 2021). Both species are often found in riverine areas with sandy conditions or small pebbles (Harding et al. 2019).

Diversity index

The Shannon-Wiener diversity index is shown in Figure 4. Shannon-Wiener diversity index shows the ecological stability of a habitat indicated by the species number found in a community; if the number of species in a community is high, it can be said that the habitat is in good condition (Ulmaula et al. 2016). Conversely, if the species diversity is low, it can be ascertained that the species occupying the habitat cannot live properly. There were 9 species at station 1 in Wonogiri with a Shannon index value of 1.66, while station 2 in Sukoharjo, there were 9 species with a Shannon index of 1.79, station 3 in Surakarta with 10 species and Shannon index of 2.08, station 4 in Karanganyar with 5 species and Shannon index of 1.39 and station 5 in Sragen with 12 species and Shannon index of 2.10.

The upper Bengawan Solo River has substrate characteristics of mostly fine sand and mud (Tyas and Widiyanto 2015) while gastropods mostly live in coarse sand or mud sediments. Most gastropods found along the river had several similarities, so the substrate occupied by these gastropods was almost the same. However, when the rainfall is high, and the water level increases, many gastropods attached to the riverbank are flooded, but most are still alive. The Shannon-Wiener diversity index can be used to compare difference in species diversity among sites (Putra et al. 2015). The high diversity index at station 5 in Sragen, with an index value of 2.10, is because this site was abundant in nutrients, had suitable substrates for various species, and suitable temperatures, so that many species can adapt well. Diversity index also indicates water quality in the habitat. This high diversity is also supported by data from BBWS (*Balai Besar Wilayah Sungai*) in November 2023, showing that the Sragen station produced a Dissolved Oxygen (DO) value of 6.3 mg/L and a BOD of 1.6 mg/L. That shows the dissolved oxygen is high and the BOD content is low, so the gastropod diversity is high. This follows Ayu et al. (2015) that the lower the BOD levels and the higher the dissolved oxygen levels in the water, the better for gastropod respiration, resulting in the higher the gastropod diversity. The higher the species diversity, the better the water quality, and vice versa (Prabandini et al. 2021), and the symbiosis created among species also affects the high diversity of species in a habitat (Muhammad 2020).

Meanwhile, the lowest value of the Shannon diversity index was at station 4 in Karanganyar with a value of 1.39. Only 5 species were found at this station, indicating that some species cannot adapt quickly or move to more suitable habitats, reducing biodiversity. Based on data from BBWS in November 2023, it was found that the Dissolved Oxygen (DO) value at Karanganyar station was 1 mg/L, and the BOD was 2.1 mg/L, which shows that the DO is low, but the BOD content is higher than the Sragen station, so the gastropod diversity is low. According to Farid et al. (2023), higher BOD content indicates a lack of dissolved oxygen in the water, which will impact the diversity of gastropods. In addition, the soil structure and substrate in Karanganyar are physically unsuitable for gastropods, namely dry and coarse sand, so only certain species can survive in this habitat.

The presence of gastropod species in a water body cannot be assumed that the high diversity of gastropod species in an area will indicate its water quality. The presence of gastropod species does not necessarily indicate that a water body has water quality above the standard quality (Nadaa et al. 2021). Other factors, including the composition of native and invasive species in a habitat eventually leads to invasive species dominating the habitat and reducing the diversity of native species (Partaya and Setiati 2022). In addition, there is a lack of vital resources such as water quality, food intake for gastropods, and unsuitable reproduction sites for the species (Lasari and Harahap 2022).

Dominance index

The dominance index describes a species' dominance over other species in an ecosystem community. The higher the dominance index value of a species, an ecosystem is dominated by certain species, vice versa if the dominance index value is low, the community is evenly composed by various species (Nahlunnisa et al. 2016). According to Ridwan et al. (2016), dominance is expressed as the species richness of a community and the balance of the number of individuals of each species found. The dominance index of ≤0.5 means that almost no species dominates (low), while the index of more than 0.5 and less than 1 means high dominance index. The dominance index in this study is included in the low category, suggesting that almost no species dominated at each observation station (Figure 4). Overall, the dominance index across all stations was 0.2 where at station 1 (Wonogiri) the index was 0.24, station 2 (Sukoharjo) was 0.21, station 3 (Surakarta) was 0.14, station 4 (Karanganyar) was 0.28, station 5 (Sragen) was 0.14.

Station 1 in Wonogiri had a sandy substrate. In addition to being easily carried by water currents and experiencing dryness when the low tide periods, gastropods will choose a habitat that is easy to use as a place to live due to the adaptability to stick to rocky substrates in tidal areas. Certain gastropod species can only achieve those survival abilities, which will affect dominance parameters (Beni et al. 2020). Station 2 composed with a lot of grass, causing gastropod diversity to be higher than that at stations 1 and 4 and the dominance at this station was also higher when compared to stations 3 and 5. This indicates that some gastropods eat grass, rice, and other weeds; hence, the amount of weed distribution around affects the intensity of gastropods found (Awang et al. 2023). The highest dominance value was found at station 4 in Karanganyar due to the presence of muddy substrate and a lot of grass, which are favorable by fewer gastropods (Abubakar et al. 2018).

Station 3 in Surakarta had a fine sandy substrate and was muddy. The dominance shown at station 3 was lower when compared to other stations and the diversity level is high. Similarly, station 5 had dominance index lower than other stations. According to Hulopi et al. (2022), the dominance index that is close to 0 and is included in the low category indicates that there is no dominance of certain species of gastropods or that the community is in a stable state. Station 5 had the highest diversity index and lowest dominance compared to other stations, except for station 3. This result indicates that Sragen has a good substrate, namely rocky, muddy sand, and grass, that can support the vegetation and breeding of gastropods (Parorrongan et al. 2018).

The main factors affecting the number of organisms, species diversity, and dominance include the destruction of natural habitats, such as land conversion, chemical and organic pollution, and climate change (Mardi et al. 2019). Therefore, compared to the other stations, station 5 in Sragen had the lowest dominance index along with station 3 due to the low organic content of the substrate, so only certain gastropods can survive. Stations 3 and 5 had a mixed substrate of sandy mud, allowing carnivorous, detritus-eating scavenger gastropods to be found. Meanwhile, herbivorous or algae-eating gastropods will likely be found very little along Bengawan Solo. Algae-eating gastropods can only be found in areas with rocky substrates (Gea et al. 2019). In addition, residential areas far from the river basin make this river able to maintain abiotic factors suitable for the life of biota, especially gastropods.

Figure 4 shows that stations with high Shannon-Wiener diversity index values tend to have lower Simpson's dominance index. For example, Stations 3 and 5 had high diversity values (2.08 and 2.15) but low dominance values (0.14 and 0.14), respectively. This indicates a high variety of species but low dominance of one or few particular species. Conversely, stations with low Shannon-Wiener diversity index values tend to have higher Simpson's dominance index values (Nahlunnisa et al. 2016). Stations 1, 2, and 4 had lower Shannon-Wiener index values (1.79, 1.66, and 1.39) but higher dominance values (0.21, 0.24, and 0.28). According to Partlova et al. (2020), the Shannon-Wiener index measures the total diversity of species, while Simpson's dominance index focuses on the dominance of a particular species. Thus, there is an inverse relationship between these two indices at the study stations; the higher diversity (Shannon-Wiener index), the lower dominance (Simpson index), and vice versa. Ashton and Macintosh (2002) explain that the high dominance of one species may indicate a stressful environment, while higher diversity indicates stable conditions in the ecosystem. Inter-species competition is among the most influential factors; therefore, a species dominating a particular environment can reduce overall diversity. Furthermore, the presence of invasive species can alter ecosystem dynamics, reducing diversity by displacing native species and increasing the dominance of certain species (Borden and Flory 2021)

Gastropods density

Gastropod density indicates the number of individuals living in a certain habitat, area, and time (Persulessy and Arini 2018). Irawan (2008) stated that the density value is a parameter of the quality of a habitat; a high-density value indicates that the habitat is very suitable for the life of organisms. This indicates that a large number of organisms can occupy the habitat. The density index is shown in Table 3 and Figure 4.

Table 3. Gastropod species density index in the upper Bengawan Solo River, Central Java, Indonesia

Species names	Stations				
	1	2	3	4	5
Tarebia granifera (Lamarck, 1816)	5.13	1.88	0.05	1.23	0.63
Pomacea canaliculata (Lamarck, 1822)	0.16	0.12	0.11	0.93	1.22
Semisulcospira libertina (A. Gould, 1859)	0.92	0.67		2.63	
Melanoides tuberculata (O.F. Muller, 1774)	1.36	0.56		0.92	0.31
Filopaludina javanica (Busch, 1844)	0.36	0.07	0.22		0.26
Sulcospira testudinaria (Busch, 1842)	3.87	1.11	0.43		0.97
Stenomelania punctata (Lamarck, 1822)		0.35			
Stenomelania denisoniensis (Brot, 1877)	0.27				
Viviparus intertextus (Say, 1829)	0.25				
Sermyla riquetii (Grateloup, 1840)	1.33				
Pila scutata (Mousson, 1848)			0.23		
Pila ampullacea (Linnaeus, 1758)		0.08			0.27
Faunus ater (Linnaeus, 1758)			0.6		
Limicolaria flammea (O.F. Muller 1774)			0.12		
Achatina immaculata (Lamarck, 1822)			0.1	0.25	0.08
Acavus phoenix (L. Pfeiffer, 1854)			0.3		
Segmentina nitida (Strom, 1765)			0.18		
Viviparus viviparus (Linnaeus, 1758)					1.46
Cipangopaludina chinensis (J.E.Gray, 1833)					0.05
Littorina litorea (Linnaeus, 1758)					0.26
Viviparus glacialis (S.V. Wood, 1872)					0.45
Zebrina detrita (O.F. Muller, 1774)					0.07
Brotia costula (Rafinesque, 1833)		0.4			
Total	13.65	5.24	2.34	5.96	6.25

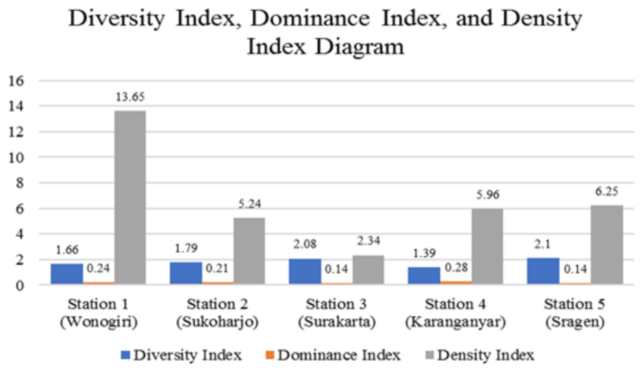

Figure 4. Diversity index, dominance index, and density index of gastropod species found in the upper Bengawan Solo River, Central Java, Indonesia

Species with the highest density at station 1 were *T. granifera* (5.13 ind./m^2), *S. testudinaria* (3.87 ind./m^2), *M. tuberculata* (1.36 ind./m^2) and *S. riquetii* (1.33 ind./m^2). Species with the highest density at station 2 were *T. granifera* (1.88 ind./m^2) and *S. testudinaria* (1.11 ind./m^2). The species with the highest density at station 3 was *F. ater* (0.6 ind./m^2). Species with the highest density at station 4 were *S. libertina* (2.63 ind./m^2) and *T. granifera* (1.23 ind./m^2). Species with the highest density at station 5 were *V. viviparus* (1.46 ind./m^2) and *P. canaliculata* (1.22 ind./m^2).

Table 3 shows that among high-density species are invasive alien species, namely *T. granifera, S. testudinaria, M. tuberculata, S. riquetii, S. libertina, F. ater, V. viviparus,* and *P. canaliculata.* The presence of invasive gastropods will pose a significant potential threat to the ecosystem. These invasive species accidentally enter and live outside their native range. The dominance of invasive alien species can pose a threat by disturbing the balance of ecological system and can lead to the loss of local species, so the existence of invasive alien species could threaten aquatic biodiversity in Bengawan Solo River (Sirza et al. 2020). The presence of invasive gastropod species in rivers will potentially threaten native gastropod species, destroy the ecosystem, and threaten public health as well as agriculture (Li et al. 2023). The spread of invasive alien species is one of the significant threats to the biodiversity of native aquatic fauna (Diagne et al. 2021). Invasive alien gastropods have high reproduction ability which threatening aquatic and terrestrial ecosystems (Jiang et al. 2022). Due to their high appetite, high reproductivity, and dispersal ability, invasive gastropods can alter nutrient balances and cause rapid changes in aquatic and terrestrial ecosystem communities. Wittenberg and Cock (2001) stated that invasive alien species also impose enormous costs on the fisheries sector besides threatening biodiversity. In addition, many invasive gastropods carry bacteria and parasites that, when handled by humans with bare hands or eaten, potentially pose a significant threat to human health (Mazza et al. 2014). Therefore, prioritizing monitoring and controlling invasive alien gastropods are necessary in the Upper Bengawan Solo River. Conservation strategies can be carried out to control invasive alien species, such as developing appropriate regulations and eradication methods appropriately (Purnama et al. 2022b).

Figure 4 shows that stations 1, 2, and 4 had lower diversity index values and higher dominance indices compared to the other two stations. Concurrently, there three stations had species with high-density values. The number of species found in these stations was relatively small compared to other two stations, resulting in the high dominance index, where the greater the density value, the greater the tendency of one species to dominate the population (Gea et al. 2019). Stations 3 and 5, with higher diversity index and lower dominance index, had more species found, and species with the highest density did not have a large gap with other species. According to Odum (1994), a community has high species diversity if the community is composed of many species with the same abundance. Conversely, if the community is composed of very few species, and if only a few species are dominant, then the diversity is low.

In conclusion, there were 23 species from 9 families of gastropods in the upper Bengawan Solo River including 16 invasive species and 7 native species. The diversity and dominance of species among the five stations differed due to differences in substrate types (such as sandy, muddy, or rocky) and abiotic factors. The diversity of gastropods found at all research stations was classified as moderate (1.39-2.10) while the dominance index was in the low category (0.14-0.28), indicating no dominant species. Factors that influence both indices include habitat diversity, environmental pressure, competition between species, the presence of invasive species, predator-prey interactions, diversity of nutrient sources, and land use and environmental management. Some invasive gastropod species such as *T. granifera, S. testudinaria, M. tuberculata, S. riquetii, S. libertina, F. ater, V. viviparus,* and *P. canaliculata* had high density compared to other species. The high density of invasive alien gastropods can pose a threat to the ecological integrity of aquatic ecosystem in the upper Bengawan Solo River and might lead to the loss of native species.

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Diversity of *Ficus* (Moraceae) along the riparian zone of Samin River, Central Java, Indonesia

ALVINA NOVELINDA KUSUMA[1], FADHIL ACHMAD ZAKY[1], THAARIQ RIAN PRIBADY[1], YONANDA SURYA AGUSTIN[1], GILANG DWI NUGROHO[2], ARU DEWANGGA[1], AHMAD DWI SETYAWAN[1,3,♥]

[1]Department of Environmental Science, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia. Tel./fax.: +62-271-663375, ♥email: volatileoils@gmail.com
[2]Biodiversity Study Club, Faculty of Mathematics and Natural Sciences, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia
[3]Biodiversity Research Group, Universitas Sebelas Maret. Jl. Ir. Sutami 36A, Surakarta 57126, Central Java, Indonesia

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Abstract. *Kusuma AN, Zaky FA, Pribady TR, Agustin YS, Nugroho GD, Dewangga A, Setyawan AD. 2024. Diversity of* Ficus *(Moraceae) along the riparian zone of Samin River, Central Java, Indonesia. Intl J Bonorowo Wetlands 14: 96-104.* Riparian vegetation plays an immense role in maintaining the hydrological and ecological functions of a river. One eminent vegetation species with great importance in riparian zone is the group of *Ficus* or figs. Many *Ficus* species occur in riparian ecosystems including in the Samin River, which stretches from Karanganyar to Sukoharjo Districts, Central Java, Indonesia and empties into the Bengawan Solo River. This study aimed to determine the diversity of *Ficus* along the riparian zone of Samin River from the upstream to the downstream. Data collection used a survey method at six stations by cruising a path with length of 1 km at each station and observing the right and left side of the river with a radius of 5-10 meters. All *Ficu*s species, abiotic factors, altitude, and coordinates of the location point were recorded. Data was analysed to calculate Shannon-Weiner diversity index (H'), Evenness index (E) and Margalef species richness index (R). The results of the study documented 7 *Ficus* species, namely *F. racemosa* (34 individuals), *F. septica* (32 individuals), *F. fistulosa* (22 individuals), *F. benjamina* (11 individuals), *F. elastica* (1 individual), *F. microcarpa* (1 individual) and *F. virens* (1 individual). Species diversity index, evenness index and richness index at the upstream, middlestream and downstream sections ranged 0.54-0.88 (low diversity), 0.41-0.80 (uneven-almost even), and 0.52-0.61 (low richness), respectively. *Ficus* in the Samin River occurred in the habitat with air temperature of 21-38.4°C, humidity of 73-97%, and soil pH of 7-7.2. The findings of this study imply that riparian zone along the Samin River comprises a considerable diversity of *Ficus* which can maintain river sustainability.

Keywords: Biodiversity, *Ficus*, riparian zone, Samin River

INTRODUCTION

Biodiversity is the variety of living beings that includes plants, animals, and the various genetic materials contained in them, as well as the ecological factors that affect them (Hardiwinoto et al. 2024). According to Lewinsohn and Jorge (2024), species diversity is the basic component of biodiversity. Assessments on biodiversity are commonly carried out by focusing on specific taxonomic groups, taking into account the number and relative abundance of species. It is important to evaluate species diversity at different spatial scales to identify which patterns are visible at each scale and what factors may determine them. Other aspects, such as phylogenetic, functional, and interactional diversity, contribute to improved assessments of the dynamics in species diversity due to environmental change and their consequences for ecosystem services that are important for human subsistence and well-being.

Rivers are aquatic ecosystems that have important roles for humans and other organisms. Riparian areas deliver various ecological functions, including protection for regional biodiversity, climate regulation, water protection, and nutrient filtration. These ecological functions are directly related to the vital ecosystem services provided to society. Many of these functions have direct economic relevance, including support for agriculture, forestry, industry, and recreation such as waterfalls, hiking, canoeing, and fishing (González et al. 2017). In providing such ecological services, there are several biotic and abiotic factors that should present in riparian zone, one of which vegetation diversity. Riparian area with large proportion of vegetation cover combined with great number of species diversity will maintain the ecological functions of the river. According to Zeng et al. (2019), riparian plant diversity is influenced by groundwater depth, distance from the river, soil moisture content, and soil salinity.

One of the riparian biodiversity in the form of trees that is important to support the hydrological function of rivers is plants of the genus of *Ficus* or figs group (Izzati and Hasibuan 2019). In term of ecological aspect, *Ficus* provides twice as many benefits as other vegetation, indicating that conserving and using *Ficus* to restore degraded ecosystems is more effective than other species (Hendrayana et al. 2022). *Ficu*s species can initiate and facilitate the regeneration of plant communities in a landscape that not only supports the spread of fruiting plants but can also develop new compositional structures (Dewi et al. 2023). Many species from the genus of *Ficus* have the habitat in riparian ecosystems with widespread distribution throughout Indonesia, one of which is Samin River, which stretches from Karanganyar District to Sukoharjo District and empties into the Bengawan Solo River, Central Java, Indonesia. Bengawan Solo has 28 sub-watersheds, including the Samin River.

Bengawan Solo watershed has experienced a decline in many of its ecological functions caused by several factors, including changes in land use and low public environmental awareness (Fatimah et al. 2023). Samin River has high biodiversity, especially in the upstream part on Mount Lawu slope which has distinctive flora and fauna. However, the great economic potential in the upper Samin River causes tremendous pressures on land use. There are increasing trends of forest encroachment for agricultural activities, construction of houses on steep slopes, and changes in land use from natural landscape into built-up area to harness tourism opportunities by developing hotel facilities, villas, homestays, and coffee shops. The middle part of the Samin River located in Karanganyar District is characterized with the presence of agricultural land and semi-urban area with the diversity is relatively maintained. The downstream area of Samin River, which is the meeting point with Bengawan Solo River in Sukoharjo District, is dominated by urban residentials, reducing the ecosystem quality compared to the upstream.

The variation of biodiversity that exists in the Samin River, starting from the upstream, middle, and downstream with differences and factors that influence it, has not been widely studied, especially for taxonomic group which has great ecological importance such as *Ficus* or figs. Therefore, this research is aimed to identify the diversity of *Ficus* along the banks of the Samin River. We expected the results of this study are useful for understanding the ecology, distribution, and diversity of *Ficus* in Samin River which might serve as baseline information for river management and biodiversity conservation.

MATERIALS AND METHODS

Study area

The research was conducted in March 2024 in several areas of the Samin River, Samin River, Central Java, Indonesia. Samin River is geographically located between the coordinates of 110°46′35″ E - 111°10′42″ E and 7°26′43″S - 7°43′00″ S. Samin River has an area of about 63,494.85 ha with a river length of 53.8 Km. Data collection was conducted in three stations, divided into 6 villages, from the upstream to the downstream before it empties into the Bengawan Solo River. In the upstream part of the river, we selected the river section in Blumbang and Tlogo Dringo Villages, Karanganyar District, then for the middlestream, Plosorejo and Girilayu Villages were choosen, Karanganyar District and in the downstream was in Kadokan and Mojolaban Villages, Sukoharjo District (Table 1, Figure 1).

Samin River meanders through various types of land, ranging from dense tropical rainforests to cultivated farmland. The area surrounding the Samin River showcases diverse habitats, including primary forests, secondary forests, agricultural land, and urban areas. Its geographical conditions and tropical climate make it a suitable environment for the growth and development of various plant species, including members of the Moraceae family, such as the genus *Ficus* (Noviyanti et al. 2021).

Data collection

Data collection used a survey method along the river with length of 1 km at each station by exploring and observing the right and left of the river at a radius of 5-10 meters from the cruising path. During the exploration, each *Ficus* species was recorded along with the number of individuals, and abiotic factors such as air temperature, humidity, soil pH, altitude and coordinates. Identification of each type of *Ficus* species was based on the morphological characteristics, referring to available literature, such as journals and books, as well as taxonomical databases, such as Berg and Corner (2005) and Global Biodiversity Information Facility (GBIF).

Data analysis

Data analysis was carried out descriptively regarding the information of the species, its ecological functions in riparian areas, abiotic factors, and the ecological index of *Ficus* found. We also calculated ecological indices to describe the diversity and distribution of organisms within an ecosystem to provide an overview of the health and stability of an ecosystem and to monitor changes in biodiversity over time. The ecological indices were analyzed based on the diversity index of the Shannon-Wiener index (H'), Evenness index (E) and Margalef species richness index (R).

Table 1. Research location and coordinates in Samin River, Central Java, Indonesia

Location		Station	Coordinate
Upstream	Blumbang Village, Karanganyar District	1	7° 39' 3.2076" S, 111° 9' 31.158" E
	Tlogo Dringo Village, Karanganyar District	2	7° 40' 23.4732" S, 111° 11' 21.0768" E
Middlestream	Girilayu Village, Karanganyar District	3	7° 39' 17.892" S, 111° 4' 55.6104" E
	Plosorejo Village, Karanganyar District	4	7° 38' 39.9732" S, 111° 2' 59.0244" E
Downstream	Kadokan Village, Sukoharjo District	5	7° 35' 58.4448" S, 110° 49' 59.4876" E
	Mojolaban Village, Sukoharjo District	6	7° 35' 57.768" S, 110° 50' 0.8052" E

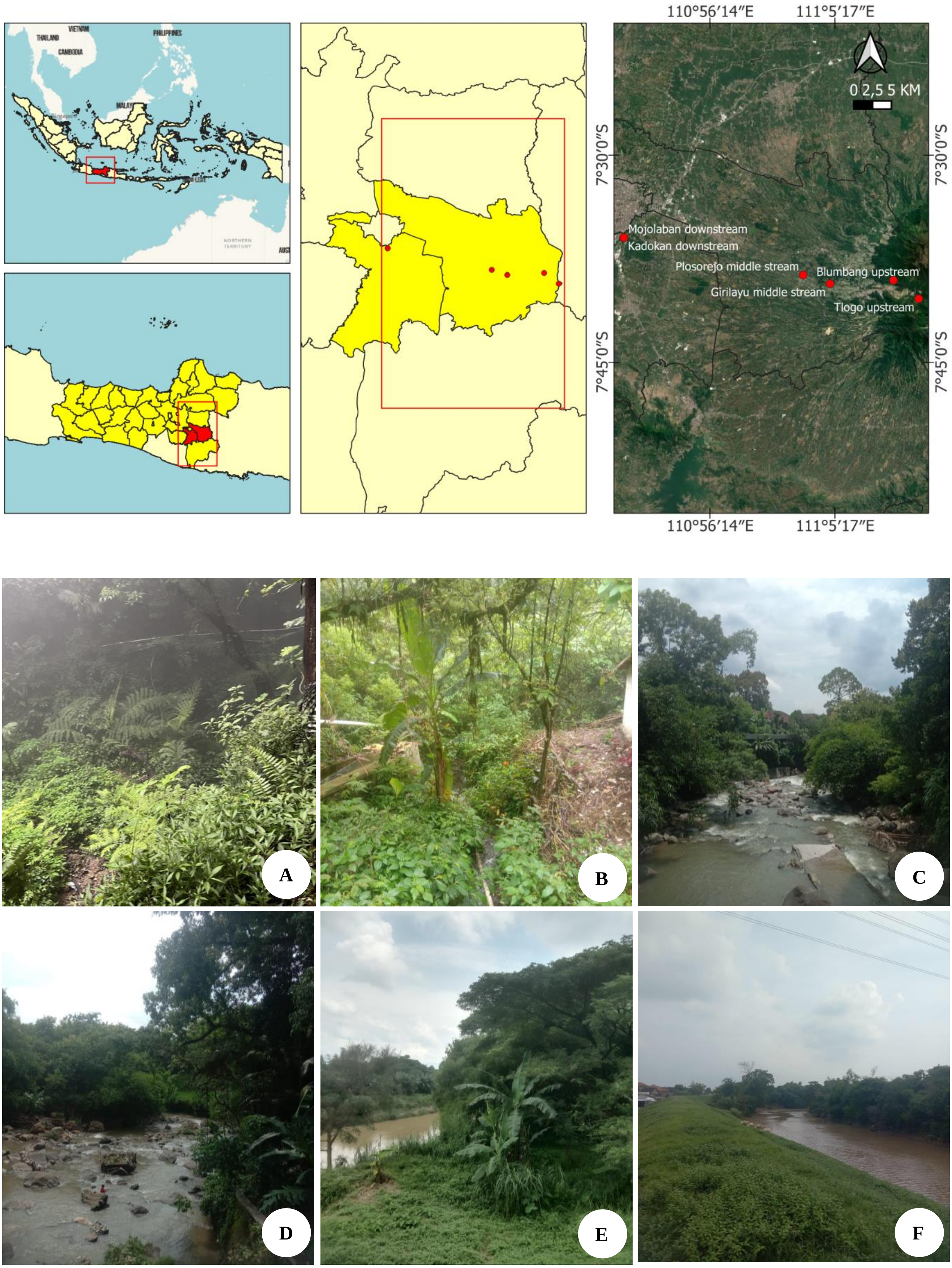

Figure 1. Map of research locations along the Samin River in Karanganyar (A; B; C; D) and Sukoharjo Districts (E; F), Central Java, Indonesia. The photograph shows each station at: A. Blumbang Village; B. Tlogo Dringo Village; C. Girilayu Village; D. Plosorejo Village; E) Kadokan Village; F. Mojolaban Village

Shannon-Wiener index (H') was calculated using formula below (Kim et al. 2017)

$$H' = -\sum(Pi \ln Pi)$$

Where: H': Shannon Wiener Diversity index (H'); ni: The number of individuals or important values of type I; S: The total number of species found; N: Individual total or total importance of all types

The range of Diversity index (H') was classified as:

H >3: High diversity; 1 ≤ H ≤ 3: Medium diversity; H < 1: Low diversity

Evenness index (E) was calculated based on Strong (2016) as follow:

$$E = \frac{H\prime}{lnS}$$

Where: E: Evenness index; H': Shannon Wiener Diversity index (H'); S: Total number of species discovered

Evenness index was categorized as:

0.00-0.25: Uneven; 0.26-0.50: Not evenly distributed; 0.51-0.75: Fairly even; 0.76-0.95: Almost even; 0.96-1.00: Equally

Margalef Species Richness index (R) was calculated using the formula based on Lemos et al. (2023):

$$R = \frac{S-1}{\ln(N)}$$

Where: R: Richness index; S: Total number of species discovered; N: Total number of individuals found

Margalef species richness index was classified as:

R < 3.5: Low species richness; 3.5 ≤ R ≤ 5: Moderate Species Richness; R > 5: High Species Richness

RESULTS AND DISCUSSION

Diversity of *Ficus* along the Samin River

The observation results are presented in Table 2, revealing the identification of 7 *Ficus* species (Figure 2), namely *Ficus fistulosa* Reinw. ex Blume (22 individuals), *Ficus benjamina* L. (11 individuals), *Ficus racemosa* L. (34 individuals), *Ficus virens* Aiton (1 individual), *Ficus septica* Burm.fil. (32 individuals), *Ficus microcarpa* L.fil. (1 individual), and *Ficus elastica* Roxb (1 individual). *Ficus* in the Samin River was assessed across three segments: upstream, midstream, and downstream. In the upstream segment, three species were identified: *F. fistulosa* (22 individuals), *F. benjamina* (2 individuals), and *F. racemosa* (2 individuals). The midstream segment hosted three species: *F. benjamina* (8 individuals), *F. racemosa* (8 individuals), and *F. septica* (31 individuals). Lastly, the downstream segment exhibited six species: *F. benjamina* (1 individual), *F. racemosa* (24 individuals), *F. septica* (1 individual), *F. microcarpa* (1 individual), *F. virens* (1 individual), and *F. elastica* (1 individual).

Ficus benjamina was found at elevations ranging from 90 to 1554 meters above sea level (masl), while *F. fistulosa* was discovered in the upper part of the river, at elevations ranging from 1404 to 1490 masl. In the middle part of the Samin River, at elevations ranging from 85 to 624 masl, *F. septica* was found. Meanwhile, in the lower section of the Samin River, in Kadokan Village, *F. elastica* was located at 90 masl. Additionally, *F. microcarpa* was found in the lower part of the river at 83 m asl. *F. racemosa* was distributed across all stations with elevations ranging from 85 to 1758 masl. Based on this research, *F. racemosa* and *F. benjamina* can live from lowlands to highlands (above 1,500 masl), which is different with *F. fistulosa,* which can only be found in highlands. In contrast, *F. elastica*, *F. microcarpa* and *F. virens* can only found in the lowlands below 100 meters above sea level (Table 2). In the upstream section of the Samin River at Station 1 and Station 2, there were fewer *Ficus* species than in the middle and downstream sections of the river. It is in line with the research of Pothasin et al. (2014), which revealed differences in species richness, density and diversity. There are a greater number of *Ficus* species at elevations between 400-600 m above sea level. The distribution of species richness along altitudinal gradients is regulated by biological and climatic factors. Other factors, such as soil fertility, vegetation and topography, can also influence species richness patterns (Isnaini and Sukarsono 2015; Kadir 2015). Based this research, *Ficus* in the Samin River riparian area were mostly found at Stations 4, 5 and 6, which are the middle and lower reaches of the Samin River with elevation 400-1000 m above sea level.

Table 2. *Ficus* species found along the Samin River, Central Java, Indonesia

Species	Upstream		Middle		Downstream		Elevation	Habitat		Number of
	B	TD	G	P	K	M	(m asl.)	T	E	Individuals
Ficus benjamina L	✓	-	✓	✓	-	✓	90-1,554	✓	-	11
Ficus elastica Roxb	-	-	-	-	✓	-	90	✓	-	1
Ficus fistulosa Reinw. ex Blume	✓	✓	-	-	-	-	1,404-1,490	✓	-	22
Ficus microcarpa L.fil.	-	-	-	-	-	✓	83	✓	-	1
Ficus racemosa L.	-	✓	✓	✓	✓	✓	85-1,758	✓	-	34
Ficus septica Burm.fil..	-	-	✓	✓	-	-	85-624	✓	-	32
Ficus virens Aiton	-	-	-	-	✓	-	85	-	✓	1

Note: B: Blumbang Village; TD: Tlogo Dringo Village; G: Girilayu Village; P: Plosorejo Village; K: Kadokan Village; M: Mojolaban Village; T: Terestrial; E: Epifit

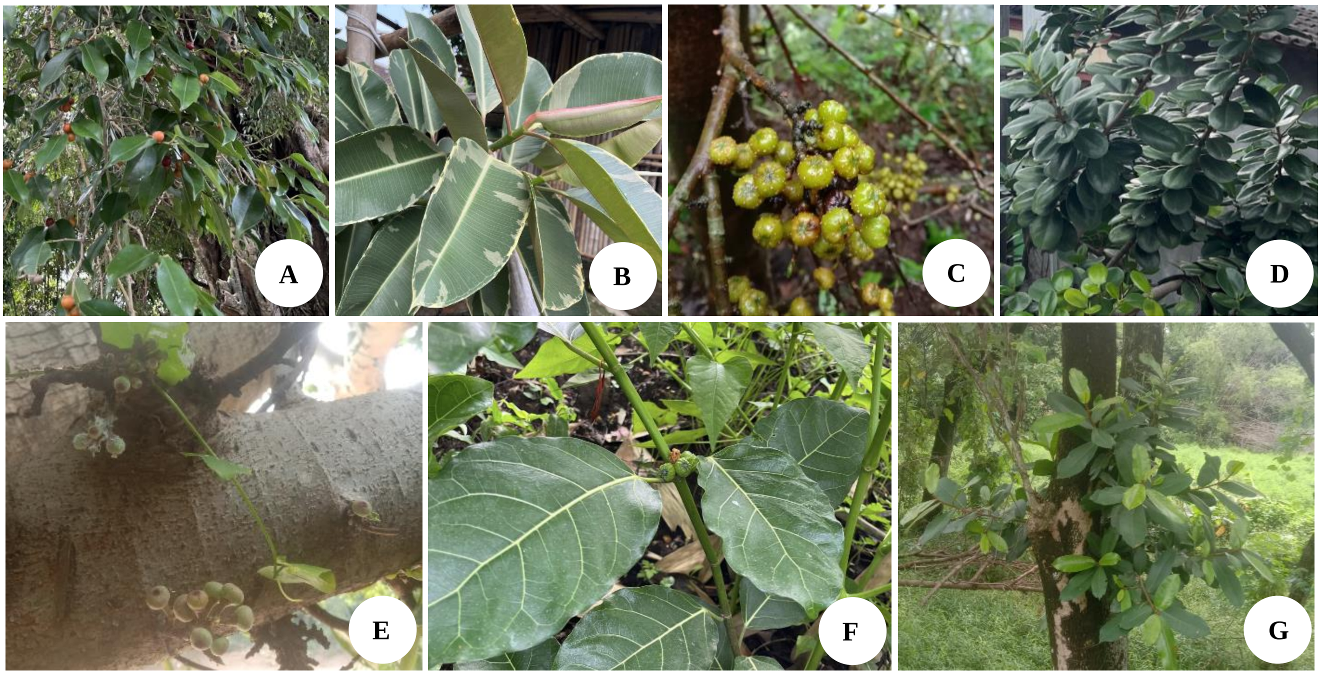

Figure 2. *Ficus* species found along the Samin River, Central Java, Indonesia: A. *Ficus benjamina*; B. *Ficus elastica*; C. *Ficus fistulosa*; D. *Ficus microcarpa*; E. *Ficus racemosa*; F. *Ficus septica*; G. *Ficus virens*

A study Fikriyya et al. (2023) located in the Banjaran River, Banyumas District, Indonesia showed that *F. septica* was found in disturbed areas, suggesting the high adaptability of this species across various habitat conditions including those disturbed by anthropogenic activities. This species can also reduce heavy metals in the soil (Mariwy et al. 2020). This is in line with the finding of this study where *F. septica* were found in the middle section of the Samin River which is located in residential areas where river condition is disturbed by water discharge. A research by Ayu et al. (2023) showed that *F. racemosa* can live in various habitats, which is similar with the finding of this study where *F. racemosa* in the Samin River can be found in the upstream, middle and downstream. Meanwhile, *F. fistulosa* grows in upstream areas because of its strong and extensive root system morphology. This is supported by Ridwan and Pamungkas (2015) and Ayu et al. (2023) which stated that in the spring area the vegetation that grows is primarily *Ficus* with roots that can reach the aquifer which can facilitate the ground flow to become springs.

Description of *Ficus* species

Ficus benjamina *L.*

From the observations and according by Hadi et al. (2019), the trunk is round and upright, and the surface is rough and blackish brown (Figure 2.A). The leaves are plain green and oval. The tops of the leaves are covered with two large scales. It has single flowers that come out and grow from the leaf axils. The petals are shaped like a funnel. They are slightly greenish-yellow in color and small in size. The fruit is small, round, 0.5-1 cm long, green when young and reddish when ripe.

Ficus elastica *Roxb*

Ficus elastica is commonly used as ornamental plant that attract attention with their large, glossy leaves (Figure 2.B). This species is native to the tropics of East Asia, although it is now spread throughout the world (Munir 2023). The plant has broad, dark green, glossy leaves. The leaf midrib contrasts with the white color. This species can grow quite large indoors if well cared for. This tree has slender, drooping branches, giving it an elegant appearance. *F. elastica* can grow well in tropical and subtropical regions, usually in lowland forests. The plant is known for its latex-containing sap that can be extracted for industrial use, especially in the production of synthetic rubber. *F. elastica* has a variety of benefits, including environmental uses, medicinal uses, and as a source of fuel and food (Dewi et al. 2023)

Ficus fistulosa *Reinw. ex Blume*

This plant grows in several tropical countries, including Indonesia (Figure 2.C). The unripe fruits are green, with a thumbnail size and spherical shape, with some flattening on top and bottom (Ditthawutthikul et al. 2021). *F. fistulosa* is tree up to 20 meters high, has branch with grey-brown trunk and white gummy, leaves are egg-shaped to oval or elliptical to lanceolate. The location of the leaves is on the stem, alternating or sitting opposite; meanwhile, young leaves of the *F. fistulosa* could be processed as vegetables or used as a forage plant for ruminants (Wijaya and Defiani 2021).

Ficus microcarpa *L.fil.*

Ficus microcarpa, commonly known as Chinese or Malay banyan or fig, is considered one of the most common urban trees in warm climates around the world (Figure 2.D). It is known as an invader species due to its ability to grow in inhospitable places, large number of fruit production, and fast spreading growth (Fiorenza et al. 2022). Traditionally, *F. microcarpa* has been used in folk medicine to treat various diseases, such as in China, *F. microcarpa* is referred to as "rong shu", used to treat flu, malaria, acute colitis, tonsillitis, bronchitis, and rheumatism, as it has pharmacological properties, including antioxidant, antibacterial, anticancer, antidiabetic, anti-diarrheal, anti-inflammatory, anti-asthmatic, hepatoprotective, and hypolipidemic activities (Kalaskar et al. 2023). *F. microcarpa* is also a riparian tree species that indicates the water quality of springs and waterways (Rambey et al. 2021).

Ficus racemosa *L.*

Ficus racemosa, which generally grows around rivers, can be used an environmental indicator of land use change (Figure 2.E) (Peniwidiyanti et al. 2022). This plant is distributed in India, Bangladesh, Myanmar, Thailand, Indonesia, Vietnam, Australia, etc. In Bangladesh, it grows in the plains and lower areas, up to 1,000 meters above sea level and well-known as medicinal plant, commonly known as *dumor* in Bengali. This plant is also known as *audumbar*, bunch fig tree, Indian fig tree or *goolar*, and has antibacterial, antitussive, anthelmintic, anti-diarrheal, anticancer, and anti-inflammatory properties (Pingale et al. 2019).

Ficus septica *Burm.fil.*

Ficus septica, also known as *awar-awar* in Indonesian, is a tree that can grow to 3-25 meters tall with a pale brown to yellowish brown trunk (Figure 2.F). The leaves are oval-ovate with a rounded base, a fairly blunt tapering tip, and a flat edge. *Awar-awar* has an important role in the ecological and hydrological functions in the riparian zone because it can grow on various soil types and is often found in secondary rainforests, bushes, roadsides, and riverbanks. This species is also pollinated by agonid wasps of the genus *Ceratosolen*, which play an important role in dispersing its seeds (Soliman et al. 2021). In addition, *awar-awar* leaves have ecological benefits as a medicine for various diseases, including skin diseases, appendicitis, boils, venomous snake bites, and shortness of breath, and the roots are used as an antidote for fish poison and asthma control (Alaman et al. 2020).

Ficus virens *Aiton*

Ficus virens is a tree that can grow to 24-27 meters in dry areas and as high as 32 meters in more humid areas (Figure 2.G) (Nair et al. 2021). This tree has a wide canopy and hanging aerial roots, which provide protection for humans and symbolize harmony between humans and nature. This species are often planted in locations that are considered sacred or holy, such as squares, springs and cemeteries, because of their deep philosophical meaning. It is a fig tree belonging to a group of trees known as strangler figs, because the seeds can germinate on other trees and grow to strangle them, eventually killing the host tree.

One of the morphological characteristics of *Ficus* is that it has an extensive root system that grows strongly into the ground and reaches the ground widely, which can play a role in soil conservation by preventing soil erosion around river flows. It also stabilises the groundwater cycle and filters groundwater to support water quality around the *Ficus* growing area (Ulfah et al. 2015). The large stature of plants and roots that can reach water areas benefit other organisms, such as aquatic animals, insects and microbial organisms maintain biodiversity in riparian areas (Vargas et al. 2023). *Ficus* produces dense fruit, which can be a source of food for several animals. Fruits that fall and rot will become a source of nutrients for the surrounding soil and the surrounding water ecosystem. The dense leaves and branches that grow thickly around river flow function as vegetation cover, which can maintain the temperature of the water and soil as well as the organisms that live in the ecosystem (Zotz et al. 2021). *Ficus* are particularly attractive to seed dispersers because they produce large and highly nutritious fruits. The effectiveness of *Ficus* trees in promoting vegetation recovery is higher than other common trees. Therefore, the conservation of *Ficus* trees should be prioritized (Cottee-Jones et al. 2016). Several *Ficus* species are also used as a traditional medicine for diarrhea, oligogalactia, and diabetes (Shi et al. 2018). *Ficus* and its species-specific pollinator wasps (Agaonidae) greatly influence community ecology by forming a remarkable plant-insect obligate mutualism (Aribal et al. 2016). *Ficus* is essential for the sustainable management of river ecosystems by increasing carrying capacity, cleaning water and stabilizing riverbanks (Raphael and Laika 2022).

Ecological indices

Shannon-Wienner (H') diversity index

The Shannon-Wiener Diversity index (H') is a measure of biodiversity that evaluates species richness (number of species) and evenness (distribution of individuals among species) (Odum 1993). When applied to *Ficus* species, the index helps assess their ecological importance and diversity within a particular habitat. Based on the Shannon-Wiener Diversity index (H') (Table 3), the highest diversity index was in the middlestream area with H' of 0.88. This value is higher than the average *Ficus* diversity found by Purba et al. (2015) with H' of 0.6. A low Shannon-Wiener Diversity index indicates low biodiversity in a given ecosystem, meaning the ecosystem either has few species (low richness) and the number of individuals was almost uniform (Rohman et al. 2023). Diversity includes two main dimensions, the variation in the number of species and the number of individuals of each type in an area. At each location, the abundance of each species varies quantitatively because some species are much more important than others, resulting in high and low diversity of ecosystems (Hasan et al. 2020).

Evenness index

The evenness index measures the degree of evenness of individual species abundance within a community. Evenness indicates the balance and stability of community (Adelina et al. 2016). Based on Table 4, the evenness index in the Samin River upstream is E = 0.49, indicating that *Ficus* species were not evenly distributed. Similarly, in the downstream area, with a value of E = 0.41, the distribution was not even because only two species were found in both areas. It contrasts, in the middle part of the Samin River had E value of 0.80, suggesting that *Ficus* were almost evenly distributed due to the presence of several species. *Ficus* species with effective seed dispersal agents, such as birds and bats, may dominate in numbers. Inefficient dispersal systems can limit the abundance of certain species, lowering evenness (Nakabayashi et al. 2019). Low evenness often reflects ecological imbalance or dominance by a few species well-adapted to the environment (Rohman et al. 2023).

Richness index

According to Baderan et al. (2021), the greater number of species found in a community the greater the richness index. However, the richness index indicates that the increase in the number of species is inversely proportional to the number of individuals. Table 5 shows that the *Ficus* richness index at the upstream station is 0.61, falling into the low category and indicating that the number of *Ficus* species was relatively few. Similarly, the *Ficus* richness index at the midstream and downstream stations are 0.52 and 0.59, respectively, falling into the low category. These results suggest that the Samin River has a relatively low number of *Ficus* species and an uneven distribution. It may be due to various factors, including climatic conditions, topography, and interactions with other vegetation (Isnaini and Sukarsono 2015). Similar studies conducted in other areas, such as in the Satui Sub-watershed, South Kalimantan, Indonesia (Kadir 2015), have shown that vegetation composition and structure also influence the potential of vegetation as a parameter for hydrology and soil erosion.

Abiotic factor of Samin River

Based on the observations, the abiotic factors in the *Ficus* habitat along the Samin River vary across stations (Table 6). In the upper section at Blumbang Village, the air temperature was 21-23.8°C with 89% humidity and a soil pH of 7 while at Tlogo Dringo, it was 22-23°C, 97% humidity, and soil pH of 7. In the middle section at Girilayu Village, the temperature increased to 25-28°C with 87% humidity and a soil pH of 7, while at Plosorejo Village was at 28-29°C with 79% humidity and a soil pH of 7.2. In the lower section at Kadokan Village, the temperature increased to 30-38.4°C with 73% humidity and a soil pH of 7, while at Mojolaban Village, it was 30-38°C with 73% humidity and a soil pH of 7. The lower section generally exhibited higher air temperatures than the upper and middle segments.

Abiotic parameters (air temperature, soil pH, air humidity) are very important factors that influence the distribution of *Ficus* in the Samin River. The measurement of abiotic parameters aims to determine the physical conditions of aquatic ecosystems that support *Ficus* diversity. The temperature in this study, which ranged from 23-30°C, is in line with Yuan et al. (2024), who stated that in the native habitat, many *Ficus* species are found in warm regions, but they can also withstand short periods of cooler temperatures, especially when dormant. Low humidity levels lead to increased transpiration (water loss through the leaves), which can stress the plant. This can result in dried tips or edges on the leaves and overall reduced plant vitality. *Ficus* may exhibit leaf drop in response to prolonged dry air, as a survival mechanism to reduce water loss (Yuan et al. 2024), so a high humidity is an ideal for their health.

Table 3. Shannon-Wienner Diversity index (H') of *Ficus* in Samin River, Central Java, Indonesia

Stations	H'	Category
Upstream	0.54	Low
Middlestream	0.88	Low
Downstream	0.74	Low

Table 4. Evenness index of *Ficus* in Samin River, Central Java, Indonesia

Stations	Evenness index	Category
Upstream	0.49	Not evenly
Middlestream	0.80	Almost even
Downstream	0.41	Not evenly

Table 5. Richness index of *Ficus* in Samin River, Central Java, Indonesia

Stations	Richness index	Category
Upstream	0.61	Low
Middlestream	0.52	Low
Downstream	0.59	Low

Table 6. Abiotic factors in the habitat of *Ficus* in the Samin River, Central Java, Indonesia

Station		Air Temperature (°C)	Air Humidity (%)	Soil pH
Upstream	Blumbang Village (1)	21-23.8°C	89%	7
	Tlogo Dringo (2)	22-23°C	97%	7
Middlestream	Girilayu Village (3)	25-28°C	87%	7
	Plosorejo Village (4)	28-29°C	79%	7.2
Downstream	Kadokan Village (5)	30-38.4°C	73%	7
	Mojolaban Village (6)	30-38°C	73%	7

In riparian zones, where *Ficus* are often found, soil pH is influenced by the presence of river water and organic matter. In these areas, *Ficus* species contribute to soil stabilization and the provision of organic matter, but changes in pH due to erosion or human activity can disrupt their distribution locally (e.g., in the forests of Thailand and Borneo) (Pothasin et al. 2014; Nakabayashi et al. 2019). The pH results in this study were within the optimal range, i.e. from 7 to 7.2. *Ficus* also exhibit tolerance to varying soil pH, depending on the specific needs of the species. Some *Ficus* species, such as *F. benjamina* and *F. elastica*, are more commonly found in environments with neutral to slightly acidic soil pH because this pH match supports microbial activity that aids in decomposition and nutrient release (Nakabayashi et al. 2019; Gaur et al. 2024).

In conclusion, the study documented 7 *Ficus* species along the Samin River, namely *F. fistulosa* (22 individuals), *F. benjamina* (11 individuals), *F. racemosa* (34 individuals), *F. virens* (1 individual), *F. septica* (32 individuals), *F. microcarpa* (1 individual), and *F. elastica* (1 individual). The species diversity index, the species evenness index and the species richness index obtained in the entire Samin River (upstream, middlestream and downstream) are 0.54-0.88 (low), 0.41-0.80 (uneven-almost even), and 0.52-0.61 (low), respectively. The *Ficus* recorded in this study occurred in habitat with air temperature of 21-38.4°C, humidity of 73-97%, and soil pH of 7-7.2. The study suggests that knowledge of *Ficus* ecology, distribution, and diversity is crucial for managing rivers and preserving biodiversity in general. Knowing this allows for the implementation of suitable measures to safeguard the river environment and guarantee its sustainability.

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Freshwater fish diversity and habitat assessment with a focus on *Pethia reval* in Pusseli Oya, Kelani River Basin, Sri Lanka

P. H. M. G. C. PRIYADARSHANA♥, U. L. N. L. VIJETHILAKA, M. T. FERNANDO, S. D. PARANAGAMA
The Young Zoologists Association of Sri Lanka, The National Zoological Gardens. 120 Galvihara Rd, Dehiwala-Mount Lavinia PO: 10350, Sri Lanka.
Tel.: +94-11-4-852828, ♥email: priyadarshanachathura1@gmail.com

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Abstract. *Priyadarshana PHMGC, Vijethilaka ULNL, Fernando MT, Paranagama SD. 2024. Freshwater fish diversity and habitat assessment with a focus on* Pethia reval *in Pusseli Oya, Kelani River Basin, Sri Lanka. Intl J Bonorowo Wetlands 14: 105-111.* The Pusseli Oya, a tributary in the Kelani River Basin was investigated preliminary to assess the freshwater fish diversity with a particular focus on the endangered endemic species *Pethia reval*. This study highlights the urgent need for conservation actions to protect these unique ecosystems. Five distinct sites were selected for the study, and sampling was conducted from August to October 2024 using snorkeling, hand nets, and trawl nets complemented by measurements of physio-chemical parameters, including temperature, pH, and flow rate with anthropogenic activities. A total of 29 freshwater fish species were recorded, representing eight orders and 12 families, with Cyprinidae being the most dominant family. Among these, 10 species were endemic, highlighting the area's ecological importance. *P. reval* was recorded at most of the selected sampling sites but was absent in one sampling site, which displayed a lower pH and increased anthropogenic activities than other sites. These conditions and the presence of aquatic plants likely impacted the species' distribution, emphasizing its sensitivity to habitat disturbances. Findings reveal that sites with stable water quality and minimal anthropogenic influence are essential for sustaining diverse fish populations and conserving *P. reval* and other endemics. This research underscores the need for immediate area-based conservation actions to mitigate human impacts and maintain ecological balance within the Kelani River basin. Those area-based conservation activities will contribute to broader conservation throughout the country with a special focus on range-restricted and nationally important freshwater fish fauna on the island. Future studies should focus on longitudinal assessments to strengthen conservation strategies for Sri Lanka's endemic and native freshwater fish.

Keywords: Endemic, freshwater fish, Kelani River Basin, *Pethia reval*, preliminary study

INTRODUCTION

Sri Lanka has a diverse network of freshwater habitats across 103 river basins and man-made ecosystems. To date, Sri Lanka hosts a total of 127 species of freshwater fish, with 61 endemic and 30 introduced to the island (Goonatilake et al. 2020). Pethiyagoda and Sudasinghe (2021) noted that the wet zone contains 70 species of freshwater fish, followed by the intermediate zone (46) and dry zone (36), emphasizing the role of geographical and environmental diversity in shaping freshwater diversity in Sri Lanka. However, Sudasinghe et al. (2020) show that the nomenclature of Sri Lankan freshwater fish has been extensively revised during the past two decades, and many freshwater fish genera have been revised in order to evolutionary relationships.

Based on the distribution pattern of freshwater species (Senanayake and Moyle 1982) identified four major ichthyological provinces in Sri Lanka; the Southwestern, Mahaweli, Transition, and Dry Zone. The Mahaweli and southwestern ichthyological zones have the highest species diversity among the four zones. This is due to the high heterogeneity of the habitats, rainfall patterns, and topography of this region (Thilakarathne and Hirimuthugoda 2022). The Southwestern Province is demarcated in the south by the Nilwala River and the North by the Attanagalu Oya River. This region is recognized as a hotspot for endemic freshwater species. Yet, much of this biodiversity exists outside the current protected areas and faces significant risks of habitat degradation and other anthropogenic pressures (Thilakarathne and Hirimuthugoda 2022). Other than the well-known main drivers of biodiversity loss, including habitat degradation, habitat fragmentation, habitat conversion, climate change, and invasive alien species, sand mining has resulted in the extinction or reduction of the population of freshwater fish in Sri Lanka (Goonatilake et al. 2020).

The Kelani River is the second longest river in Sri Lanka, with 20 sub-basins that flow through seven districts of the country, starting from the Adam's Peak Mountain in southwestern Sri Lanka and ending in Colombo, the western part of the country (Goonatilake et al. 2016; Abeysinghe and Samarakoon 2017). The Kelani River is the most polluted river on the island, with severally degraded water due to domestic and industrial waste, agricultural runoff, soil erosion, saltwater intrusion, and flood inundation despite being the primary water source of drinking water for the residents of the river basin, host to many aquatic species and is utilized for many industries, agricultural activities, power generation, recreation, fisheries, tourism, and gem and sand mining (Abeysinghe and Samarakoon 2017; Mahagamage and Manage 2017). This river basin is spread within the Southwestern ichthyological Province, where more than half of Sri

Lanka's endemic freshwater fish are harbored. Surasinghe et al. (2020) documented a total of 60 freshwater fish species in the Kelani River basin, including 30 endemic species. Tributaries of the Kelani River cover the Colombo district, while semi-urban and rural areas of the Colombo district still provide habitat for the inland freshwater fish in Sri Lanka, with over 40 species having high endemism including range-restricted *Pethia reval* (Sudasinghe et al. 2014). Appropriate habitat assessments for those nationally important faunas should be evaluated, and a database on those habitat assessments is currently needed in Sri Lanka. The main threats to the native fish diversity in Colombo and its outskirts areas are water pollution, habitat loss, destruction of aquatic vegetation, exotic fish species, and other anthropogenic activities (Bandara et al. 2019).

Within the Kelani River basin, the Pusseli Oya tributary and other similar streams provide high ecological significance for aquatic life in the region (Goonatilake et al. 2016). Given the concerns, the Pusseli Oya tributary represents a critical study area for assessing both biodiversity and environmental health. Hence, this study was conducted in the Pusseli oya tributary to understand the freshwater distribution, including *P. reval*, and assess physio-chemical parameters and anthropogenic activities in the area. By focusing on Pusseli Oya, this research will contribute to assessing unique freshwater fish distribution, conservation efforts needed, and sustainable management practices for these small streams in the Kelani River basin in Sri Lanka.

MATERIALS AND METHODS

Study area

Pusseli Oya is a major tributary of the Kelani River basin starting from the hills in Pusselihena Hills and situated in the southwestern ichthyological province of Sri Lanka (Goonatilake et al. 2020). Five different sites along the stream were randomly identified as study sites, and each site was chosen not to overlap with another with focus on anthropogenic activities, i.e., Point A (6°51'17.30" N, 80°4'45.97" E), Point B (6°51'29.13" N, 80°4'43.46" E), Point C (6°51'34.45" N, 80°4'45.81" E), Point D (6°51'47.58" N, 80°4'47.11" E), Point E (6°52'1.64" N, 80°4'43.07" E) (Figure 1). Human settlements, rubber plantations, and shrub areas bordered the stream selected for the study.

Procedure and data analysis

The fishers were observed from August to October 2024, covering dry spells and second inter-monsoon climatic seasons by bank-side observation in shallow water areas by snorkeling, using hand nets and small trawl nets during the daytime (Sutherland 2006). Several factors were considered in the microhabitats of the selected sampling sites with 250 m intervals between each site, such as width, depth, flow rate, temperature, pH, bottom, and shade, including the presence of anthropogenic activities. Physio-chemical parameters of water were measured in each sampling session: temperature, pH using digital meters (Test range: 0.0-14.0PH, Resolution: 0.01PH Error: ±0.05PH, Operating temperature: 0 - 80°C), flow rate using a standard float, and depth and width using a standard measuring tape. Fish species were photographed using a Nikon D7200 DSLR camera, and collected individuals were released to their habitat after being photographed. The species were identified using field expert knowledge and following standard field guidebooks. Data was analyzed using the general Microsoft Office Professional Plus 2024 package functions.

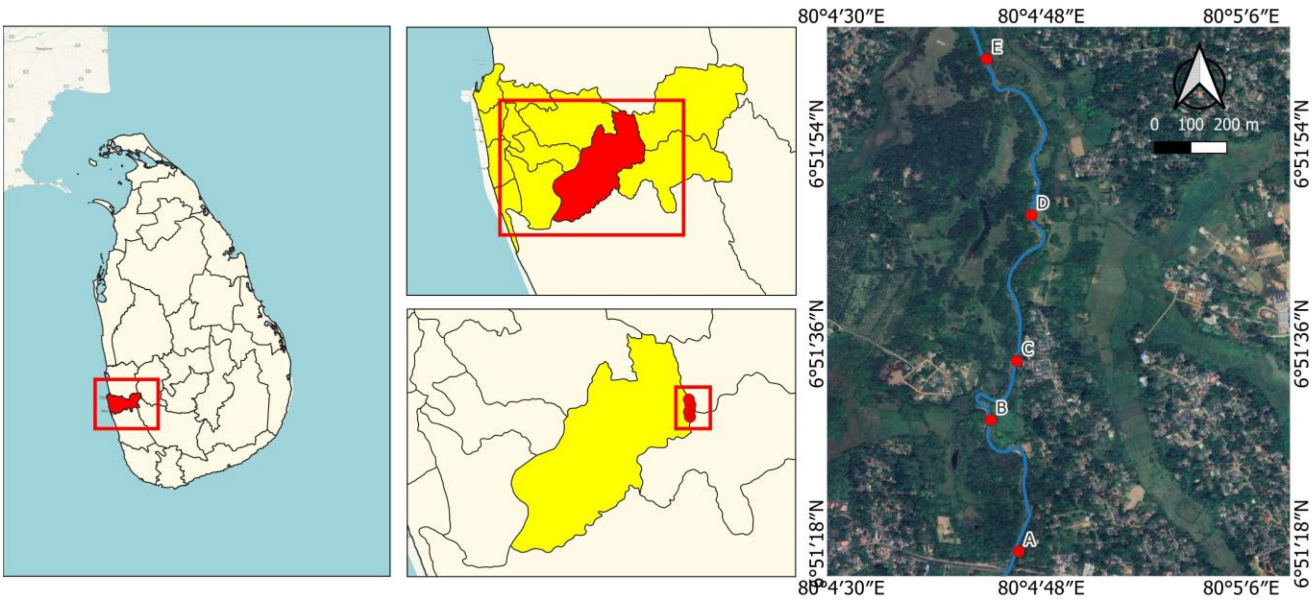

Figure 1. Sampling sites in Pusseli Oya, Kelani River Basin, Sri Lanka. Note: refer to text for point A-E

RESULTS AND DISCUSSION

The physio-chemical parameters of the selected sampling (Table 1) demonstrated significant variations, which are critical for assessing ecological health and biodiversity in an ecosystem. Site B recorded the largest width (14.56 m) with a depth of 1.04 m, indicating a more substantial water volume that may enhance habitat availability for aquatic flora and fauna. In contrast, Site A exhibited the smallest width (7.81 m) and shallowest depth of 0.5 m. Flow rates varied, with Site C recording the highest rate at 0.52 ms^{-1}, where Site B had the lowest flow rate (0.19 ms^{-1}), which could lead to stagnation and reduced oxygen levels. Temperature readings for sampling sites ranged from 28.8 (Site A) to 30.9°C (Site D), while pH values varied from 5.95 at Site C to 6.74 at Site A. The substrate composition differed among the sites as per the observation of the research team, with sandy substrate at Sites A and D and muddy conditions at Site B, while Site C contained a mix of both conditions. These variations could influence habitat structure and the assembling of freshwater fish fauna along the tributary. Additionally, shade conditions were present in Sites C and D with significant riparian canopy cover, which can positively affect the water temperature and light availability. Notably, anthropogenic activities (sand mining, pollution, day-to-day activities, etc.) were significantly higher at Site A compared to Site B, indicating a potential influence on water quality and habitat integrity. The aquatic plant distribution across the sampling sites (except Site D) supports habitat suitability for freshwater fish and ecosystem functioning in the water stream.

A total of 29 fish species belonging to eight orders and 12 families were recorded within the selected sampling points across the stream (Table 2). Among them, 10 species are endemic to Sri Lanka (Goonatilake et al. 2020). Family Cyprinidae was the most dominant fish family (13 species = 44.8%) in the study area (Figure 2), followed by families Aplocheilidae, Bagridae, Channidae, Gobidae and Cyprinidae (2 species = 6.9% each). Among the recorded species, 10 (34.5%) are endemic to Sri Lanka, including *Aplocheilus dayi*, *Mystus nanus*, *Mystus zeylanicus*, *Channa orientalis*, *Horadandia atukorali*, *Laubuka varuna*, *P. reval*, *Puntius thermalis*, *Paracanthocobitis urophthalma* and *Ompok argestes*. *A. dayi*, *P. reval*, and *P. urophthalma* are listed as locally Endangered. In comparison, *C. orientalis*, *H. atukorali*, *L. varuna*, and *O. argestes* are listed as Vulnerable fish species in Sri Lanka (Goonatilake et al. 2020). The highlighted factor is the global Red List™ provides evidence that all the endemic species recorded have declining population trends according to (The IUCN Red List of Threatened Species 2024).

Table 1. Physio-chemical parameters of water and human activities of sampling sites in Pusseli Oya, Kelani River Basin, Sri Lanka (measures in average)

Sampling site	Width (m)	Depth (m)	Flow rate (ms^{-1})	Temp (C°)	pH	Bottom	Shade	Human activities	Aquatic plants
A	7.81	0.5	0.35	28.8	6.74	Sandy	-	++	+
B	14.56	1.04	0.19	30.3	6.25	Muddy	+	-	+
C	9.70	1.32	0.52	29.4	5.95	Muddy and Sandy	-	++	+
D	9.41	0.62	0.27	30.9	6.32	Sandy	+	+	-
E	12.37	1.24	0.31	30.7	6.02	Muddy	+	-	+

Note: ++: Plentiful, +: Not much, -: Nil

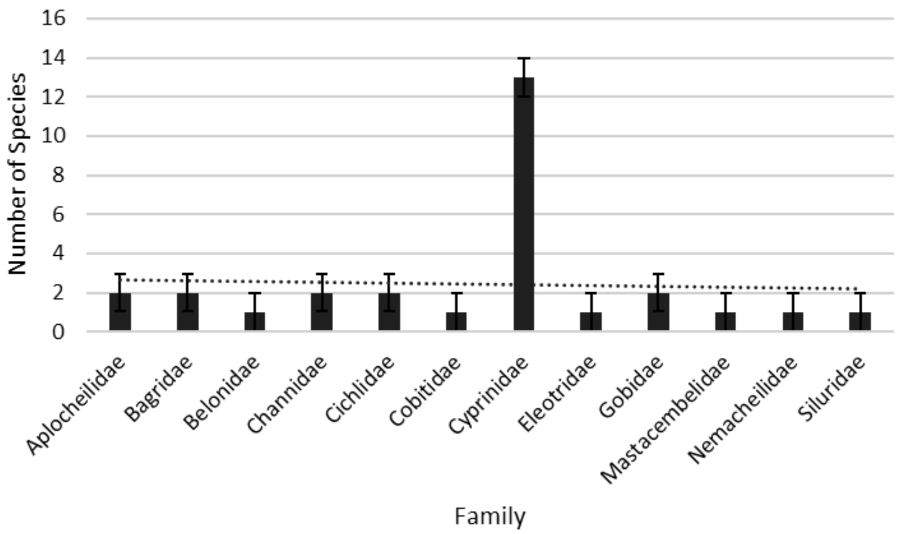

Figure 2. Number of species recorded by family during the study in Pusseli Oya, Kelani River Basin, Sri LankaLanka

Table 2. Recorded fish species on sampling sites in Pusseli Oya, Kelani River Basin, Sri Lanka

Family	Species name	Common name	Endemism in SL	NCS	Site				
					A	B	C	D	E
Aplocheilidae	*Aplocheilus dayi* Steindachner, 1892	Day's killifish	Endemic	EN	*	*		*	
Aplocheilidae	*Aplocheilus parvus* (Sundara Raj, 1916)	Dwarf panchax		LC	*	*		*	
Bagridae	*Mystus nanus* Sudasinghe, Pethiyagoda, Maduwage & Meegaskumbura, 2016	Striped dwarf catfish	Endemic	LC			*	*	*
Bagridae	*Mystus zeylanicus* Ng & Pethiyagoda, 2013	Sri Lanka mystus	Endemic	LC				*	
Belonidae	*Xenentodon cancila* (Hamilton, 1822)	Freshwater garfish		LC	*	*	*	*	*
Channidae	*Channa orientalis* Bloch & Schneider, 1801	Smooth breasted snakehead	Endemic	VU				*	
Channidae	*Channa striata* (Bloch, 1793)	Murrel		LC		*			
Cichlidae	*Etroplus suratensis* (Bloch, 1790)	Green chromide		LC		*			*
Cichlidae	*Pseudetroplus maculatus* (Bloch, 1795)	Orange chromide		LC	*			*	
Cobitidae	*Lepidocephalichthys thermalis* (Valenciennes, 1846)	Common spiny loach		LC	*			*	
Cyprinidae	*Dawkinsia filamentosa* (Valenciennes, 1844)	Filamented barb		LC	*	*	*	*	*
Cyprinidae	*Devario malabaricus* (Jerdon, 1849)	Giant danio		LC	*	*	*	*	*
Cyprinidae	*Puntius vittatus* (Day, 1865)	Silver barb		LC	*	*		*	
Cyprinidae	*Esomus thermoicos* (Valenciennes, 1842)	Flying barb		LC		*			
Cyprinidae	*Rasbora dandia* (Valenciennes, 1844)	Striped rasbora		LC	*	*	*		*
Cyprinidae	*Rasbora microcephalus* (Jerdon, 1849)	Common rasbora		LC	*	*	*	*	*
Cyprinidae	*Horadandia atukorali* Deraniyagala, 1943	Hora dandia	Endemic	VU	*	*			
Cyprinidae	*Laubuka varuna* Pethiyagoda, Kottelat, Silva, Maduwage & Meegaskumbura, 2008	Western laubuka	Endemic	VU				*	
Cyprinidae	*Pethia reval* (Meegaskumbura, Silva, Maduwage & Pethiyagoda, 2008)	Red-fin two-banded carplet	Endemic	EN	*	*		*	*
Cyprinidae	*Puntius dorsalis* (Jerdon, 1849)	Long-snouted barb		LC	*			*	*
Cyprinidae	*Puntius thermalis* (Valenciennes, 1844)	Swamp barb	Endemic	LC				*	*
Cyprinidae	*Systomus sarana* (Hamilton, 1822)	Olive barb		LC			*	*	*
Cyprinidae	*Tor khudree* (Sykes, 1839)	Mahseer		LC					*
Eleotridae	*Eleotris fusca* (Forster, 1801)	Brown gudgeon		LC				*	
Gobidae	*Awaous melanocephalus* (Bleeker, 1849)	Scribbled goby		LC	*	*		*	
Gobidae	*Glossogobius giuris* (Hamilton, 1822)	Bar-eyed goby		LC		*			
Mastacembelidae	*Mastacembelus armatus* (Lacepède, 1800)	Marbled spiny eel		LC	*			*	
Nemacheilidae	*Paracanthocobitis urophthalma* (Günther, 1868)	Tiger loach	Endemic	EN		*		*	
Siluridae	*Ompok argestes* (Sudasinghe & Meegaskumbura, 2016)	Wet zone butter catfish	Endemic	VU				*	

Note: NTS: National Threaten Status (Goonatilake et al. 2020), LC: Least Concerned, NT: Near Threatened, VU: Vulnerable, EN: Endangered, *: presence in the sites

The variations in human activities and physio-chemical parameters among sample locations have a significant impact on aquatic ecosystems and species distribution. Our research has revealed significant differences in water quality between sampling locations, a result of both natural and man-made influences. For instance, Sites A and B, despite their moderate differences in water depth and flow rate, do not support aquatic plants and have minimal human activity in Site B and high human activity in Site A, respectively. This finding underscores the crucial role of aquatic plants, even in sites with different substrate types like muddy or sandy bottoms, which is important for providing habitat and food resources for various freshwater fish species (Maitland and Lyle 1991). On the other hand, Site C, with its more acidic pH (5.95), is notable for a small amount of aquatic plants and experiencing considerable anthropogenic activities, which reduces species richness compared to other areas. Allan et al. (2020) show that human activities and water quality changes, particularly in pH can disrupt aquatic habitats and impact stream fish populations. The distribution of aquatic plants provides suitable habitats and food items to other aquatic organisms, especially fish (Ismail et al. 2018). The distribution of aquatic plants is linked to aquatic species richness, as the presence of aquatic vegetation correlates with higher biodiversity in freshwater ecosystems (Law et al. 2019). The increase in habitat volume may support a diverse range of flora and fauna by offering more space for species to thrive (Kowarik 2018). These findings have significant implications for the management and conservation of aquatic ecosystems, highlighting the need for further research and action in this area.

Flow rate variability is important because flow rates determine oxygen availability and sediment transport, hence directly influencing habitat structure and the distribution of species (Allan et al. 2020). The lower flow rate at Site B may stagnate and reduce oxygen levels, which may stress aquatic species. This is important to note for those species with higher oxygen demand, like the family Cyprinidae, which dominated study sites (Goonatilake et al. 2020). Besides, the lower flow rates can promote the settlement of pollutants and degrade water quality, thereby lowering the stream's general ecological health (Koushali et al. 2021). The temperatures were also varying among the sites, with a minimum of 28.8±°C at Site A and a maximum of 30.9±°C at Site D. Temperature has been considered one of the most important parameters affecting metabolic rates, breeding patterns, and species distribution in freshwater ecosystems (Christensen et al. 2021). Furthermore, the substrate type is one of the critical elements for habitat formation, while it strongly influences water filtration, oxygenation, and the availability of shelters for fish species. Sites with sandy substrates would probably be better for burrowing and nesting species, while muddy substrates are capable of trapping pollutants and reducing habitat quality (Christensen et al. 2021). In Sites B, D, and E, shade was available due to riparian vegetation, thus moderating the water temperature and improving water quality because of the reduction in direct sunlight. Generally, shade cover would have a positive impact on aquatic habitat and increase of fish population because of its controlling effect on algal growth and maintenance of habitat integrity (Misteli et al. 2022). Significantly, high human activities have been attributed to a decrease in both water quality and species richness (Feisal et al. 2023). For instance, the suspected anthropogenic activities around Site C are the disposal of waste and a high volume of water extraction that could explain the absence of more sensitive species like *P. reval*.

The high dominance of the species belonging to the family Cyprinidae across sites further enforces the ecological importance of this family in Sri Lankan freshwaters. Most of these species have a greater chance to survive in the environment changes and, hence, are common in disturbed habitats. However, the incidence of endemic species, which are mostly threatened, could indicate the need to focus on conservation practices to save the habitats of such species (Muluneh 2021). This unique freshwater ecosystem supports a few other endangered native fish species each having specific ecological requirements and habitat sensitivities. As an example, *P. reval* is represented in Deduru oya to Kelaniya Basin in slow and stagnant water flows (Pethiyagoda and Sudasinghe 2021).

Consequently, many of the recorded endemic species are specifically adapted to the physio-chemical conditions of freshwater habitats that were studied during the study and are sensitive to changes in water quality, and habitat structure. Moreover, human-induced activities reported in the area, like sand mining, agricultural runoff, and clear-cutting of riparian vegetation, reduce habitat complexity and increase turbidity, which directly threatens the spawning and feeding habitats of species. Hence, the restricted distribution and sensitivity to human activities call for specific conservation measures that should be taken to protect unique freshwater biodiversity (Cantonati et al. 2020). The survival of such species will not only maintain the ecological balance but also preserve the genetic diversity that makes Sri Lanka's freshwater habitats globally significant and irreplaceable.

The correlation between aquatic plant distribution and fish biodiversity observed in this study is a significant finding that reinforces the idea the role of aquatic vegetation supporting fish assemblages is multifaceted and may act as sources of food, shelter, and breeding sites (Lal et al. 2024). However, the absence of aquatic plants at Site D recorded the highest number of species during the study. According to the site observation, the site has a sandy substrate, with moderate water flow and considerable riparian vegetation with debris along the river bank with not much human disturbance, which could lead to a high density of fish species.

The genus *Pethia* represents five species from Sri Lanka, all of which are endemic to the island. Among them, *Pethia nigrofasciata* distributed from Attanagal Oya to the Walawe River Basin. *Pethia cumingii* and *P. reval* are a paratactic species pair. *Pethia cumingii* ranges from Kalu to the Walawe basin. In contrast, *P. reval* ranges from the Kelani River to the Deduru River basin, with a translocated population in the Mahaweli River Basin. Furthermore, the other *Pethia* sp. is *Pethia bandula,* a point endemic species recorded in a narrow range of the "Galapitamda" area, "Minimaru Kolaniya," a stream connected to the Kelani River basin (Pethiyagoda and Sudasinghe 2021).

Endemic *P. reval* already listed as endangered under criteria B1ab(iii,v)+2ab(iii,v) (IUCN Red List 2019) (Figure 3) was notably recorded in large numbers at most sites except Sampling Site C, illustrating the influence of environmental factors like pH and habitat structure on species presence. Its absence at sampling Site C suggests that specific physio-chemical factors and human activities may influence its distribution. The lower pH (5.95) at site C likely plays a significant role as *P. reval* may be sensitive to more acidic environments, unlike other species present at this site, despite similar conditions.

Aquatic vegetation, which is present in Sites A, B, C, and E, is a crucial factor in the survival of the species *P. reval*, providing protection, breeding sites, and feeding potential; thus, it is a factor that helps to perpetuate the populations of the species. The absence of aquatic vegetation at Site C, along with a mix of muddy and sandy substrate, could cause a less favorable habitat, as aquatic plants provide shelter, breeding sites, and food resources, demonstrating their adaptability. However, it was found in locations with different substrates but consistently had aquatic plants (except Site D), highlighting the significance of vegetation in sustaining this species. Consequently, those habitats made up of a variety of aquatic plant life, which *P. reval* is accustomed to, generally consist of complicated, vegetated structures that support a balanced ecosystem.

Figure 3. *Pethia reval* observed in Pusseli Oya, Kelani River Basin, Sri Lanka. Photo: Chathura Priyadarshana

Another key factor that seems important regarding the distribution of *P. reval* is the flow rate. The species were found to be relatively more abundant in sites characterized by moderate flow rates. These sites maintain higher oxygen levels, a crucial factor in reducing the accumulation of pollutants and ensuring a healthy ecosystem. While a high rate of flow may interfere with habitat stability, as can be seen in Site C, a low flow rate may lead to stagnation of water, as in Site B, affecting the availability of oxygen. On the other hand, the absence of *P. reval* from Site C, with high recorded flow rates, may suggest that this species prefers sites with a moderate current, which suits their physiological requirements, matching feeding behavior. In contrast, low oxygen levels due to stagnation may also be stressful to the generally less hypoxia-tolerant *P. reval* than species with greater tolerance.

Human activities also appear to impact the occurrence of *P. reval,* which was observed in Site A, where there was also evidence of human activities as sand mining; however, the type and severity of disturbances, including sand mining and waste disposal at and around Site C could be more damaging to its ecology including habitat preference of *P. reval*. Jayaneththi and Pradeep Suranga (2014) found that *P. reval* is not found in mud-bottom substrates in the Aththanagalu Oya River Basin. Still, the current study reveals that *P. reval* can thrive in sites with sandy or muddy substrates, its presence in areas with aquatic plants, and moderate human disturbance combined with more neutral pH areas.

Pethia reval is sensitive to human disturbance, evidenced by either complete absence or very low incidence in sites with high levels of anthropogenic disturbance. For instance, sand mining reduces substrate stability and makes it difficult for territories to be established or any reproduction by species. Waste disposal, on the other hand, reduces water quality and increases the levels of contaminants, hence further stressing species with narrow ecological tolerances (Bhattacharya et al. 2019). The limited distribution of *P. reval* in disturbed sites calls upon the vulnerability of the species, as habitat conservation along with pollution control enables the protection of sensitive endemic species. Conserving these nationally important and endangered freshwater faunal species based on their home range following in-situ conservation practices could prime the increase of health of the river basin eventually. Hence, the country needs interconnected broader ecosystem management to conserve this faunal taxon, balancing co-existence with humans in the future.

Since most of the threatened and endemic freshwater fish are distributed outside the current protected area, there is a high need to protect them according to an area-based conservation strategy. Any anthropogenic activity that causes harm to these habitats and critical species needs to be clearly assessed with a community-based conservation perspective, especially focusing on knowledge sharing and capacity building on conservation and sustainable practices. When critical species are located outside of the protected areas, the local communities must be made aware of this and be involved in conservation programs. Ex-situ breeding programs, translocation, and reintroduction should be established with the aim of increasing the wild population.

In conclusion, the presence of endemic and endangered species in the sites observed with optimum water quality, pH, and minimum anthropogenic activities correspond with a greater diversity of fish species, including key endemics like *P. reval*. Conservation measures should prioritize maintaining optimal water qualities and balancing human impact and aquatic ecosystems to support the long-term survival of *P. reval* across its range. Protecting these environments is essential for maintaining the ecological balance and ensuring the sustainability of both aquatic life and communities that depend on these resources. Future resources should focus on long-term monitoring of these parameters and their relationship with fish ecology in the areas for effective management strategies with a community participation perspective on conservation and ecosystem management. Hence, the previous literature and distribution of these endemic and native species confirm our observation, and it reveals that not only *P. reval* species but also other endemic and native species in this small stream need to be conserved. Future research on identifying life cycles, species-based habitat preferences, and potential area-based conservation measures are needed.

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