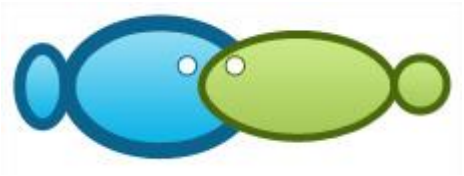

Seasonal dynamics of three invasive gastropods in urban streams of the Babura River in Medan City, Indonesia

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Abstract. The exponential growth of urban land use in recent decades has led to a significant increase in nutrient loading in urban streams, thereby causing considerable changes in the biological composition of these streams, including the benthic macroinvertebrate community. In the initial stage of our investigation in urban streams of Babura River, Medan City, we discovered the presence of invasive gastropods, namely *Melanoides tuberculata, Mieniplotia scabra,* and *Tarebia granifera,* all of which belong to the Thiaridae family. This study focused on evaluating the seasonal assemblages of these three invasive gastropods during the period of March 2017 to January 2018, including both dry and rainy seasons. The abundance of each gastropod varied significantly across sampling periods and seasons, with *M. scabra* being the most abundant species. The results of the two-way ANOVA indicated that seasonality was a more important factor in influencing the abundance of gastropods compared to differences in species population. Pearson's correlation test showed that the presence of each gastropod was correlated with different environmental parameters, with strong and positive correlations found between *M. tuberculata* and dissolved oxygen (DO) levels, pH, total dissolved solids (TDS), and velocity during the dry season. Temperature was negatively associated with the abundance of *M. scabra* and *T. granifera* during the dry season, and TDS was negatively associated with the abundance of *M. tuberculata* during the rainy season. Overall, this study provides insights into the ecology of invasive gastropods and their relationship with environmental parameters in Babura River.

Key Words: invasive alien species, molluscs, North Sumatra, population dynamics, seasonal variation.

Introduction. The presence of invasive alien species (IAS) in freshwater and terrestrial habitats in Indonesia is causing the displacement of native aquatic species (Early et al 2016). However, understanding and predicting the effects of non-native species can be difficult due to limited information on the identity, distribution, and ecology of invading organisms (Spear et al 2021). The consequences of species invasions can be severe, affecting biodiversity conservation, public health, and economics. Therefore, increasing our knowledge of the taxonomic and spatio-temporal distribution of non-native species is a critical goal in ecology and natural resource management (Lockwood et al 2013). Widespread non-native species in freshwater habitats are freshwater snails, which can have significant ecological effects on recipient communities and ecosystems. They can alter primary production and nutrient cycling, outcompete other community members, serve as prey for consumers, or transmit parasites to wildlife, livestock, and human health importance (Cattau et al 2016; Madsen & Frandsen 1989; Moslemi et al 2012; Preston et al 2022). Due to this diversity of interactions, non-native freshwater snails can cause undesirable impacts or provide valued ecological roles. An initial report by Sinambela et al (2019) in urban streams of Medan City identified the assemblage of invasive gastropod species in the Thiaridae family, namely *Melanoides tuberculata, Mieniplotia scabra*, and *Tarebia granifera*. Thiaridae snails are exotic species that can disrupt the ecosystem balance, especially if the area provides suitable environmental

conditions for their habitat preferences or niche. The invasive species *Melanoides tuberculata* is known for its origin from the European region and appears to be highly competitive and can outcompete native species in the locations where it has been introduced. This species can also act as a possible intermediary host for parasites that may have negative impacts on both humans and economically important fish species (Quirós-Rodríguez et al 2018). *Mieniplotia scabra* is a gastropod species with a wide native range in the Indo-Pacific region, spanning from central-east Africa to south Asia and northeast Australia (Cianfanelli et al 2016). *Tarebia granifera* consistently dominates the habitats and niches of the local gastropods and bivalves, particularly on the mainland and nearby islands of Sulawesi (Purnama et al 2020; Purnama et al 2021; Purnama et al 2022). The existence of this invasive population was not previously known, and the current project aims to determine the seasonal dynamics of their abundance and possible environmental variables that may support their growth.

Material and Method

Description of the study sites. The study was conducted at three different stations located in the Babura River watershed, Medan City, Deli Serdang Regency, Indonesia, from March 2017 to January 2018. Station 1, located in the Keci-keci Bingkawan village of the Sibolangit District, is the headwater of the river and is characterized by a low water discharge due to its source coming from seepage of water from the cliffs in the upper land. The water body is tightly covered by plant canopies, which results in low light penetration and little or no aquatic plants. Station 2, located in the Durin Pitu area of the Pancurbatu District, has a water body covered by sparse plant canopies that allow some light to penetrate through gaps. The upper land in this area is cultivated with crops that were originally wild plants. Station 3, located in the Tebing Ganjang area of the Namurambe district, is affected by sand mining activities that involve heavy equipment and trucks that directly enter and drive through the water body. These activities are particularly damaging in the Tebing Ganjang village of the Namurambe District, located after Station 3. Prior to Station 3, there are also pig farms and sand mining activities in the Pancurbatu and Namurambe districts. Observations were conducted monthly during the dry season, which included the months of March, May, July, and August 2017. The rainy season was observed during the months of September, October, November, and January 2018.

Gastropods collection. The biological sampling of gastropods was carried out using different methods depending on the substrate type. The Surber net was used in shallow rocky waters, while the Eckman grab was used on soft substrates. Gastropods that appeared on the surface were collected manually or through hand collecting in quadrants. The Surber net and Eckman grab were used to collect gastropods along with their associated substrates. The collected samples were then separated through multistage sieving using screens with a size of 0.5 x 0.5 mm and 1.0 x 1.0 mm. The gastropods were preserved in sample bottles containing 4% formalin and 70% alcohol and were later grouped based on their species and counted to determine their abundance. The species identification was aided by the experts in the Indonesian Institute of Sciences (LIPI) Cibinong, Bogor City, Indonesia.

Water sampling. The water quality of each station across seasons was determined for the following parameters: water temperature, measured using a digital thermometer (^{o}C) in situ; water velocity, measured using a light object and stopwatch (m/s) in situ; total dissolved solids (TDS), measured using a spectrophotometer (mg/L) in the laboratory; water acidity, measured using a digital pH-meter in situ; dissolved oxygen (DO) measured using a digital DO-meter (mg/L) in situ.

Statistical analysis. All numerical data were presented as means of different observation among sampling stations for monthly presentation and means of monthly observations for seasonal presentation. All graphical images and bar charts were

generated using GraphPad Prism ver. 8.0 Statistical analyses were performed using GraphPad Prism software. Significance of differences was defined at $p < 0.05$. Student's t test was utilized to signify the seasonal differences among environmental variables. A two-way ANOVA was utilized to determine the most important factors between species population and seasons that influence the abundance. A Pearson's product moment correlation test was utilized to show the relationship between environmental variables and species abundance across seasons.

Results. The physicochemical parameters of three urban streams in Babura River, Medan City were collected from March 2017 to January 2018, representing dry and rainy seasons (Table 1). The results revealed that dissolved oxygen (DO) ranged from 1.4 to 6.6 mg/L, with the highest value recorded in September 2017 or rainy season. The pH values ranged from 5.75 to 7.1, with the highest value recorded in December 2017. Total dissolved solids (TDS) concentrations ranged from 25 to 177 mg/L, with the highest value recorded in October 2017. The temperature of the stream ranged from 20.2 to 28.2 °C, with the highest value recorded in December 2017. The velocity of the stream ranged from 0.17 to 1.11 m/s, with the highest value recorded in January 2018 (end of rainy season). A Student's t-test was utilized to compare the means of different parameters between the dry and rainy seasons, as depicted in Figure 1. The results indicated that there were significant differences in the mean seasonal variations of all measured parameters, including dissolved oxygen (Student's t-test = 6.564, p = 0.0006), pH (Student's t-test = 4.465, p = 0.0043), total dissolved solids (Student's t-test = 2.978, p = 0.0247), water temperature (Student's t-test = 5.749, p = 0.0012), and current velocity (Student's t-test = 5.719, p = 0.0012). These findings showed that the seasonal changes in the streams may have a considerable impact on the physicochemical characteristics of the water, which could have implications for the assemblage of invasive gastropods.

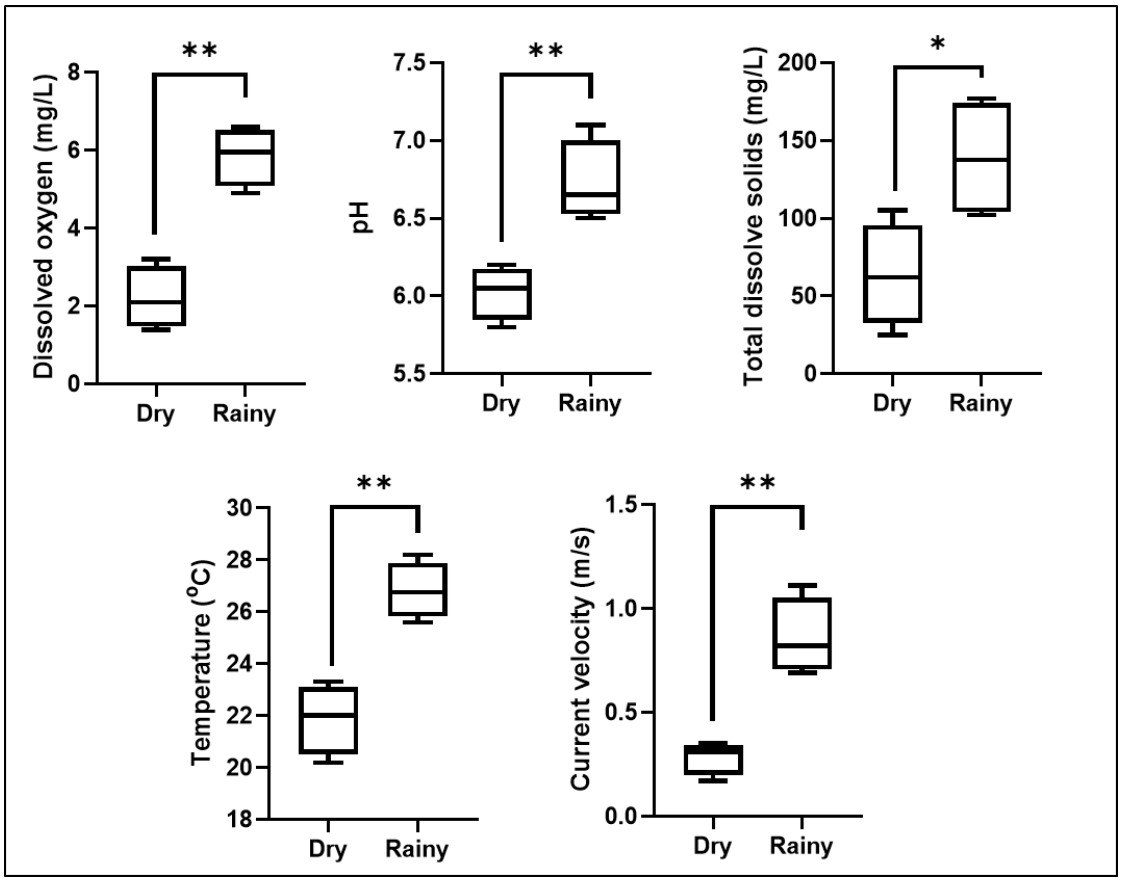

Figure 1. Seasonal variation of environmental parameters measured in three urban streams of Babura River. Student's t test was used to compare mean values among seasons, *) $p \leq 0.05$; **) $p \leq 0.01$.

Table 1
Monthly variation of environmental parameters (mean, N = 3 stations) at Babura River

Period(s)	*Dissolved oxygen (mg/L)*	*pH*	*Total dissolved solids (mg/L)*	*Water temperature (°C)*	*Current velocity (m/s)*
March-2017	1.4	5.8	25	20.2	0.29
May-2017	1.7	6.0	56	23.3	0.17
July-2017	2.5	6.1	68	22.5	0.35
August-2017	3.2	6.2	105	21.5	0.33
September-2017	6.6	6.6	110	25.6	0.69
October-2017	6.3	6.7	165	26.5	0.88
December-2017	5.6	7.1	177	28.2	1.11
January-2018	4.9	6.5	102	27.0	0.76

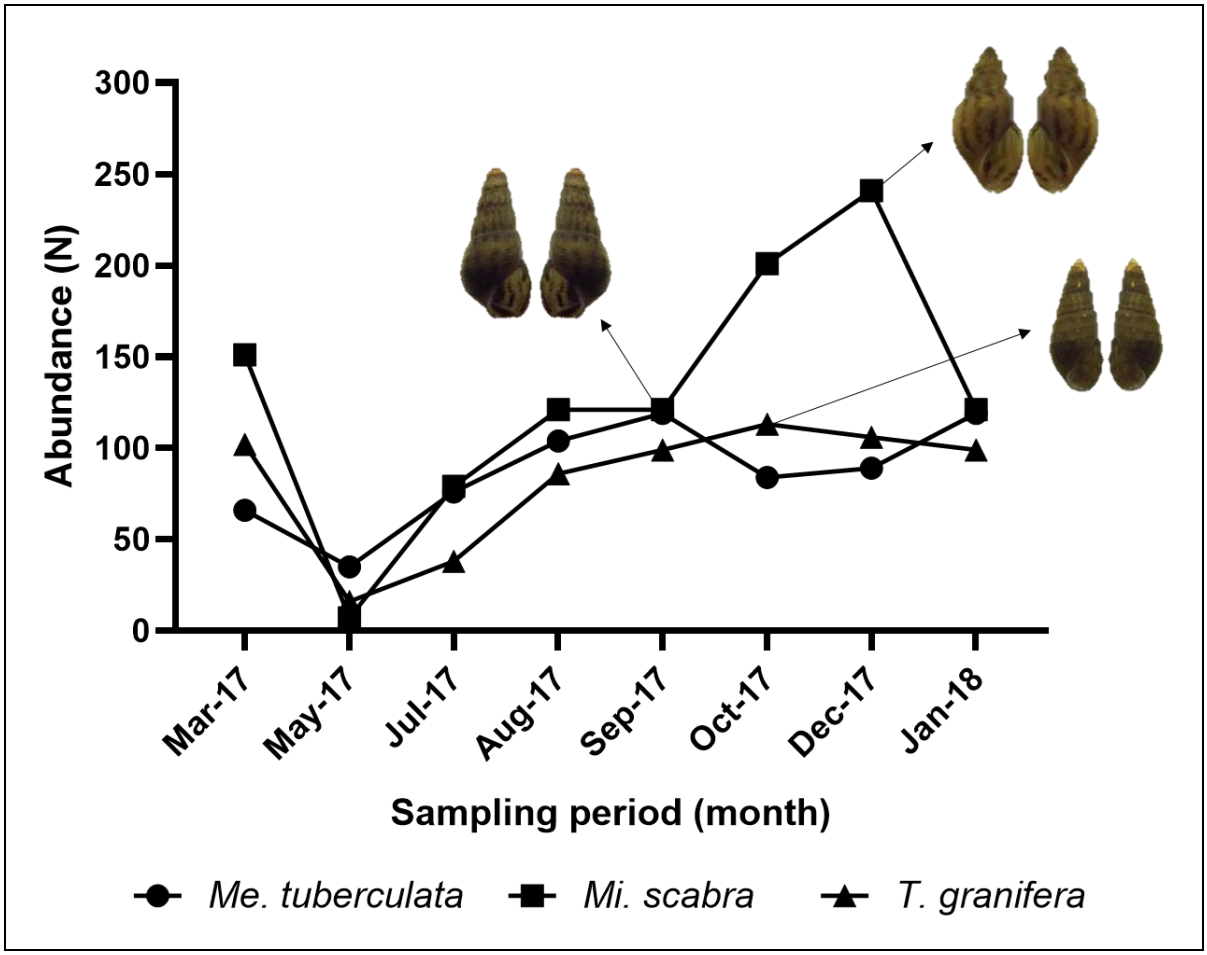

Figure 2. Temporal variation in the abundance of three invasive gastropods in Babura River.

The abundance of three invasive gastropods, *M. tuberculata*, *M. scabra*, and *T. granifera* varied significantly across the sampling periods (Figure 2). For instance, the abundance of *M. tuberculata* was highest in January 2018 (119 individuals) and lowest in May 2017 (35 individuals). In contrast, *M. scabra* showed the highest abundance in October 2017 (241 individuals) and the lowest in May 2017 (7 individuals). The abundance of *T. granifera* was highest in December 2017 (106 individuals) and lowest in May 2017 (16 individuals). The highest total abundance was observed for *M. scabra* (1042 individuals), followed by *M. tuberculata* (692 individuals), and *T. granifera* (659 individuals). The mean individuals per sampling period were 86.5 for *M. tuberculata*, 130.3 for *M. scabra*, and 82.4 for *T. granifera*. The seasonal assemblage of each gastropod is presented in Figure 3. A two-way ANOVA was utilized to compare the effect of two factors namely

species (population) and seasons to the abundance of gastropods (Table 2). The results showed that there was a significant difference in the abundance of gastropods between seasons ($F_{(1,18)}$ = 9.637, P = 0.0061). However, there was no significant interaction between species and season ($F_{(2,18)}$ = 0.7654, P = 0.4797). The abundance of gastropods between species was also found to be not significantly different ($F_{(2,18)}$ = 3.271, P = 0.0614). Based on these results, it can be assumed that seasonality is a more important factor in influencing the abundance of gastropods in Babura River compared to the differences in species population.

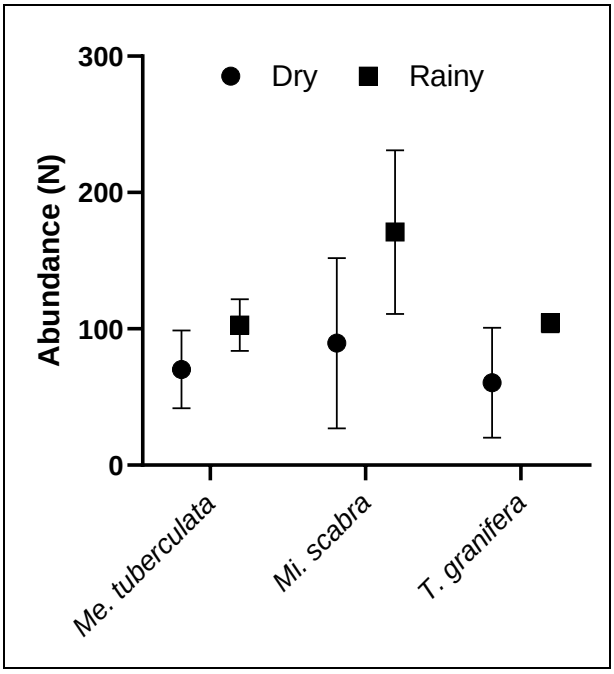

Figure 3. Seasonal variation in the abundance of three invasive gastropods in Babura River. Error bars represent standard deviations.

Table 2

Two-way ANOVA test results on the seasonal and species (population) factor and the interaction between these two factors upon the abundance of gastropods in Babura River

	df	*SS*	*MS*	*F*	*P*
Species	2	11262	5631	3.271	0.4797
Season	1	16590	16590	9.637	0.0061
Species*Season	2	2635	1318	0.7654	0.4797
Residuals	18	30986	1721		

The relationship between the abundance of three gastropod populations and environmental parameters in Babura River was examined using a Pearson's correlation test (Table 3). The values in the table represent Pearson's correlation coefficients (r), which range from -1 to 1, with 1 indicating a strong positive correlation, 0 indicating no correlation, and -1 indicating a strong negative correlation. In the dry season, there is a strong and positive correlation between the presence of *M. tuberculata* and DO (dissolved oxygen) levels (r = 0.814, P = 0.186), pH (r = 0.692, P = 0.308), TDS (r = 0.656, P = 0.344), and velocity (r = 0.860, P = 0.140). There is also a very weak and positive correlation between DO levels and the presence of *M. scabra* (r = 0.134, P = 0.866) and *T. granifera* (r = 0.080, P = 0.920), as well as a moderate and negative correlation between the presence of *M. tuberculata* and T°C (temperature of the water column) (r = -0.457, P = 0.543). Temperature is strongly and negatively associated with the abundance of *M. scabra* (r = -0.954, P = 0.046) and *T. granifera* (r = -0.969, P = 0.031) during the dry season. The presence of *T. granifera* is positively correlated with *M. tuberculata* and *M. scabra*. The positive correlation might be due to their similar habitat

preferences among species. In the rainy season, there is a moderate-to-strong and negative correlation between the abundance of *M. tuberculata* and TDS (r = -0.968, P = 0.032), temperature (r = -0.487, P = 0.513), and current velocity (r = -0.786, P = 0.214). The abundance of *M. scabra* is strongly associated to all environmental variables with significant results on TDS (r = 0.986, P = 0.014) and velocity (r = -0.953, P = 0.047). Similarly, the abundance of *T. granifera* showed a moderate-to-strong and positive correlation with TDS (r = -0.839, P = 0.161) and velocity (r = -0.548, P = 0.452) although not significant.

Table 3

Pearson's correlation coefficients between seasonal abundance of Gastropoda species and examined environmental parameters of urban streams in Babura River. Bold values are significant at P ≤ 0.05

	M. tuberculata	*M. scabra*	*T. granifera*	*DO*	*pH*	*TDS*	*T°C*	*Velocity*
Dry								
M. tuberculata								
M. scabra	0.684							
T. granifera	0.618	0.964						
DO	0.814	0.134	0.080					
pH	0.692	-0.050	-0.126	**0.977**				
TDS	0.656	-0.079	-0.077	**0.960**	**0.956**			
T°C	-0.457	**-0.954**	**-0.969**	0.135	0.326	0.309		
Velocity	0.860	0.697	0.515	0.601	0.528	0.354	-0.459	
Rainy								
M. tuberculata		-0.927	-0.945	-0.192	-0.339	**-0.968**	-0.487	-0.786
M. scabra			0.754	0.044	0.632	**0.986**	0.712	**0.953**
T. granifera				0.298	0.043	0.839	0.233	0.548
DO					0.130	0.180	-0.638	-0.205
pH						0.562	0.544	0.712
TDS							0.590	0.888
T°C								0.881
Velocity								

Discussion. The presence of invasive gastropods represented by *M. tuberculata*, *M. scabra*, and *T. granifera* from the family Thiaridae poses a threat to other aquatic biota in occupying their respective niches and ecological functions, particularly for native benthic species (Purnama et al 2020; Purnama et al 2021; Purnama et al 2022). The indication of the high abundance of these invasive gastropods may imply the current condition of organic pollution along the river at the observation location due to its proximity to human settlements (Onana et al 2019). The hypoxic condition or low dissolved oxygen (DO) observed in bodies of water during dry seasons can be attributed to the poor degradation of a significant amount of organic matter (Blaszczak et al 2023). The results of the correlation test showed a significant and positive correlation between dissolved oxygen (DO) values and pH and total dissolved solids (TDS) values. Specifically, a higher DO value was consistently associated with an increase in water pH and TDS levels. This finding suggests that ongoing anaerobic processes may be occurring in the water, resulting in the slow decomposition of nutrients that are remained into the water, contributing to increased pH and TDS levels (Liang et al 2018). On the other hand, in the rainy season, frequent rainfall may wash away the organic loads and introduce a new water column, leading to a higher DO as a method of stream self-purification (Dikeogu et al 2014).

Despite the high TDS levels observed during the rainy season, dissolved oxygen (DO) values did not exhibit a significant correlation with TDS levels. To further support this claim, it would be beneficial to accurately measure the potential nutrient loads, specifically nitrate, ammonium, and phosphate, in the water in different seasons. The invasion of these gastropod groups can be managed if adequate data on population dynamics and related environmental factors are known. Based on the obtained results, these three gastropod species appear to coexist in the research location according to the correlation analysis results that show the possibility of interspecific associations. Meanwhile, each species exhibits population dynamics in accordance with seasonal changes (dry, rainy) and monthly turnover during the observation. Members of Thiaridae are one of the IAS known to occupy all ecological niches. The majority of the studied species exhibit characteristics of trophic and habitat generalists, with relatively broad environmental tolerances in both lentic and lotic habitats (Preston et al 2022). All the invasive freshwater gastropods exhibit a relatively high "pace of life", characterized by fast growth and high reproductive potential. These traits are commonly associated with invasive species in freshwater ecosystems, as they enable rapid population growth and colonization of new habitats (Keller et al 2007). Referring to the Pearson's correlation analysis results, it can be seen that dry and rainy seasons have correlations with changes in environmental factors that contribute to the occurrence of the Thiaridae community. Environment variables that are significantly ($P \leq 0.05$) related to *M. tuberculata* only explained during the rainy season, specifically TDS's influence, as well as *M. scabra* during the rainy season.

The impact of rainfall intensity (precipitation) during the rainy season on the total dissolved solids (TDS) value in streams can have a significant influence on the abundance of invasive gastropods such as *M. tuberculata*, *M. scabra*, and *T. granifera*. The findings of this study suggest that the observed high TDS levels in the studied water bodies may be linked to high organic matter loading from urban areas. During intense rainfall events, the runoff from urban areas can transport large quantities of organic matter and nutrients into the water bodies, overwhelming the natural physical re-oxygenation processes and leading to reduced dissolved oxygen levels and increased TDS concentrations (Whitworth et al 2012; Blaszczak et al 2019). This increase in TDS can have negative consequences on native benthic species, as they may lose their ecological niche due to the presence of invasive gastropods. Furthermore, if the rainfall is too intense, it can cause flash flooding, which can wash away sediments and other materials from the surrounding landscape and contribute to an increase in TDS (Razali et al 2018). Conducting further studies in the same sites, such as surveys of different size classes or using stock assessments of Thiaridae members, may provide a more comprehensive understanding of how seasonal conditions impact the gastropod populations in Babura River. By examining different age groups, these studies may reveal how seasonal conditions either support the growth and survival of specific age groups, or lead to the elimination of entire populations, for example due to heavy rainfall and faster water velocity during the rainy season. In order to address the problem of snail fouling caused by these three invasive gastropod species, it is suggested to conduct surveys to identify potential predators such as *Anentome helena* and snail-feeding predatory fish in nearby habitats. This can serve as an initial step towards controlling the invasive snail populations, particularly during the rainy season when the problem becomes more severe (Yakovenko et al 2018). However, it is crucial to confirm whether these three species can serve as hosts for zoonotic parasites that could potentially pose a risk to human health (Boonmekam et al 2016; Nguyen et al 2021). As local communities rely on these water resources and habitats for their daily needs, it is important to ensure their safety and well-being by addressing any potential health hazards associated with these invasive gastropod species. This information may be useful for understanding the ecological dynamics of these species and informing supporting data for management of invasive gastropods of Babura River in the future.

Conclusions. The seasonal dynamics of three invasive alien species (IAS) of gastropods, *Melanoides tuberculata, Mieniplotia scabra*, and *Tarebia granifera* in the Babura River,

were characterized by high abundance during the rainy season with relatively stable populations during the observation period. *Mieniplotia scabra* exhibited the highest individual abundance during both the dry and rainy seasons, indicating that the habitat supported the species' reproduction. Environmental variables measured showed significant statistical differences across the observation months and seasons, with the most influential factors on the three gastropod populations being dissolved oxygen (DO) and total dissolved solids (TDS).

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Conflict of interest. The authors declare that there is no conflict of interest.

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