**BIODIVERSITAS** ISSN: 1412-033X
Volume 26, Number 5, May 2025 E-ISSN: 2085-4722
Pages: 2519-2530 DOI: 10.13057/biodiv/d260547

# Comparing diatom diversity over three decades in the Brantas River, Malang, East Java, Indonesia

**M. IQBAL NAJIB FAHMI, SUSRIYATI MAHANAL♥, SITI ZUBAIDAH, IBROHIM**
Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Negeri Malang. Jl. Semarang 5, Malang 65145, East Java, Indonesia. Tel./fax.: +62-341-551312, ♥email: susriyati.mahanal.fmipa@um.ac.id

Manuscript received: 23 September 2024. Revision accepted: 16 May 2025.

**Abstract.** *Fahmi MIN, Mahanal S, Zubaidah S, Ibrohim. 2025. Comparing diatom diversity over three decades in the Brantas River, Malang, East Java, Indonesia. Biodiversitas 26: 2519-2530.* Diatoms are highly sensitive to environmental changes, making them reliable bioindicators. However, there is limited research on their long-term use in the Brantas River, Malang, Indonesia. This study aimed to compare the diatom diversity of the Brantas River, over three decades. This study was conducted at five observation stations during the dry season, and the results obtained from the comparison of species richness and diatom diversity index values revealed a significant downward trend at Stations II to V from the 1990s to the 2020s. Conversely, Station I exhibited relatively stable values for species richness and diatom diversity index. The results of the comparison of the density of genera and order for three decades showed the same results, with the genera *Cocconies* and the order Pennales being the most common species found. A meticulous examination of the prevalent species at the Station I consistently yielded analogous results over the course of three decades (*Achnanthes lanceolata, Cocconeis placentula*, and *Nitzschia tryblionella*). In contrast, Stations II to V exhibited fluctuations in the predominant species with each successive decade of observation. Based on the values of species richness, diversity index, and predominant species, it is suspected that there is a decrease in river water quality at Stations II to V from the 1990s to the 2020s, but not at Station I. This phenomenon may have been caused by environmental pollution and anthropogenic activities at Stations II-V. In contrast, Station I showed relatively the same water quality because it was located in a conservation area with minimal anthropogenic human activity. This study is limited to assessing water quality based on diatom diversity. Further research is needed to assess the physicochemical properties of the Brantas River in Malang.

**Keywords:** Bioindicator, Brantas River, diatom diversity, water quality degradation

## INTRODUCTION

The Brantas River stands as a vital resource for the people of East Java, Indonesia, serving as the region's largest water supplier (Valen et al. 2020; Widodo et al. 2020; Roestamy and Fulazzaky 2022; Hasan et al. 2023). Originating from the slopes of Mount Arjuna and Anjasmara in Malang, East Java, the river winds its way to Surabaya, East Java (Arsad et al. 2021). The Brantas is the second longest river in Java after the Bengawan Solo, covering ±320 km with a drainage area of ±12,000 km² (Ismanto et al. 2022). Beyond providing clean water, the river supports local livelihood through agricultural irrigation, power generation, and tourism (Hayati et al. 2017; Khumairoh et al. 2024). Monitoring river health is crucial, particularly in the face of accelerating urbanization, agricultural intensification, and climate change in Indonesia (Januar et al. 2025; Remondi et al. 2016). One widely accepted approach to monitoring aquatic ecosystem health is through the use of bioindicators (Parmar et al. 2016). Among the most sensitive and widely used bioindicators in freshwater ecosystems are diatoms (Bacillariophyceae) (Falasco et al. 2021; Masouras et al. 2021).

Bacillariophyceae, classified as diatoms, are a group of single-celled algae characterized by silica-based cell walls (Cantonati et al. 2022). These organisms play a significant role in ecosystems, contributing to 20% of the global primary productivity and functioning as a vital link in aquatic food webs (B-Béres et al. 2023). Furthermore, this organism has been identified as a bioindicator in various aquatic ecosystems, including streams (Taxböck et al. 2020; Risjani et al. 2021). These organisms are renowned for their sensitivity to environmental changes (Solak et al. 2020; Masouras et al. 2021), thus serving as biological indicators of pollution and alterations in aquatic ecosystems (Hagan et al. 2021; Luethje and Snyder 2021).

Research on using diatoms as bioindicators is being increasingly conducted (Falasco et al. 2021; Mbao et al. 2022). This organism research is mostly used as an indicator to assess water quality and identify the impact of changes in anthropogenic activities (Zhang et al. 2019). However, the understanding of its diversity relationships is largely based on short-term observational (Supono and Hudaidah 2018; Minaoui et al. 2021; Prasertsin et al. 2021; Heikkinen et al. 2022; Soeprobowati et al. 2022), experimental (Bach and Taucher 2019; Topal et al. 2020), and modelling approaches (Coste et al. 2009), and very few studies on diatoms have been conducted over the long term (Nohe et al. 2020).

Understanding the long-term response of diatoms is important because these organisms are sensitive to environmental variables such as nutrients, water chemistry, and geographical conditions (Chen et al. 2019; Orefice et al. 2019; Kong et al. 2021; Shibabaw et al. 2021). These organisms are good bioindicators of water quality because they contain indestructible silica, have high species diversity, have a relatively short life cycle, and require a relatively simple sampling process (Mahanal 1998; Costa and Schneck 2022; Kock et al. 2023). In Indonesia, rapid urbanization and massive industrial growth have increased ecological pressure on aquatic ecosystems, including in the Brantas watershed (Salim and Hudalah 2020; Batubara et al. 2023; Basuki et al. 2024). Therefore, long-term studies on diatom diversity are needed to accurately identify trends in water quality changes and support sustainable river management (Virta and Teittinen 2022). Such long-term studies can reveal community dynamics that are undetectable in short-term observations, and help in identifying indicator species that reflect the overall health of the ecosystem (Rodríguez-Miret et al. 2023; Wiwoho et al. 2023).

The diversity of diatoms and their community trend in the Brantas River was reported by Mahanal (1998), Wibowo (2008), Masithah and Islamy (2023), and a trend of variation in their communities was reported in a previous study. However, no follow-up research has been conducted to determine the current conditions of diatoms in this area. Therefore, this study aimed to determine the diversity of diatoms in the Brantas River in Malang, Indonesia. The results of this study were compared to those of Mahanal (1998) and Wibowo (2008). This study is expected to provide new information on using diatoms as bioindicators of river water quality over time.

## MATERIALS AND METHODS

### Study area

The study was conducted along the Brantas River in Malang, Indonesia (Figure 1) in 2023 during the dry season (September to December). This season gave the possibility of obtaining optimal diatom data to represent the quality of the Brantas River water ecosystem. The study included five observational stations, each consisting of four sampling points covering the middle and side of the river (Figure 1). Season and observation location were determined according to the research of Mahanal (1998) and Wibowo (2008). Station I was located in the Brantas River spring water conservation area of Junggo Village, Bumiaji Sub-district, Batu City; Station II was situated in the agricultural and tourism areas of Junrejo Sub-district, Batu City; Station III was in a densely populated area, campus area, and home industry of Klojen Sub-district, Malang City; Station IV was in a densely populated and agricultural area of Kedungkandang Sub-district, Malang City; and Station V was in the agricultural area of Blobo Dam of Kepanjen Sub-district, Malang District. The geographical coordinates of the observation stations and detailed data on land use characteristics are shown in Table 1.

### Procedures

Diatom sampling and identification procedures were conducted according to the research of Mahanal (1998) and Wibowo (2008) in the following manner: The sampling took place in three repetitions at five stations using an artificial glass plate substrate. Diatoms have a very strong ability to adhere to the substrate, and the glass surface is slippery and rigid, which can facilitate diatom sampling (Mahanal 1998). The 15 × 10 × 0.5 $cm^3$ glass plate was used and left for 14 days with the position in the direction of the river current (Mahanal 1998; Wibowo 2008). At each observation station, four frames were installed in series, two at the edge and two in the center of the river. After 14 days, the glass plate was scraped using a toothbrush and rinsed with distilled water to a volume of 300 mL. In the following step, the water was placed in a 300 mL sample bottle, and five drops of 40% formalin were added as a preservative. The following process was performed at the Biology Laboratory of Universitas Negeri Malang, Malang.

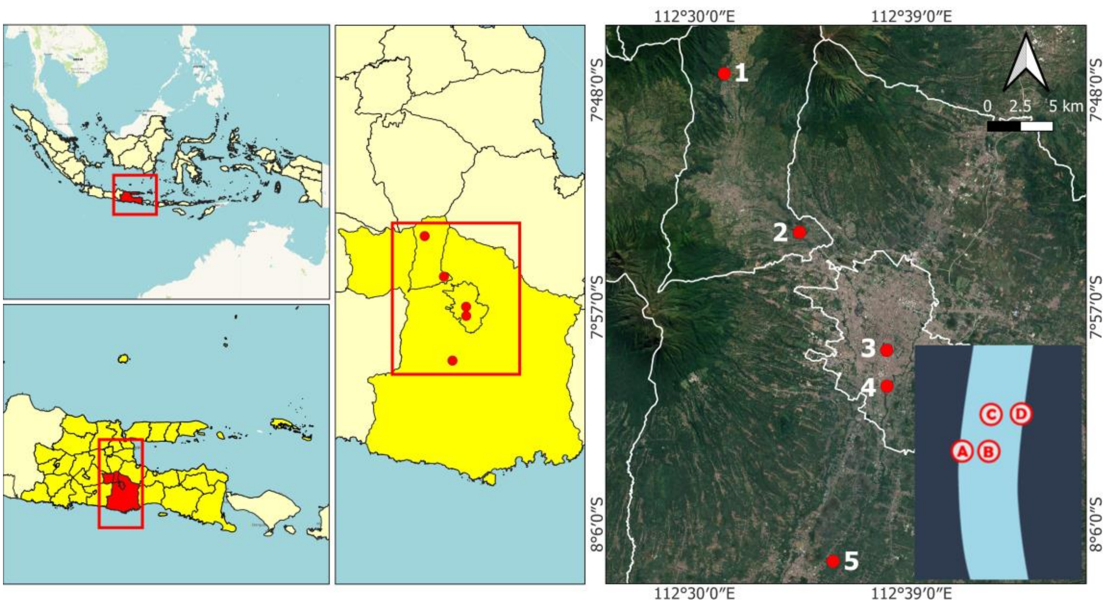


**Figure 1.** Diatom sampling location in Brantas River, Malang, East Java, Indonesia. The observation site consists of five stations, numbered 1 (Station I), 2 (Station II), 3 (Station III), 4 (Station IV), and 5 (Station V). Note: Each station consisted of four glass plate frames installed in series. The letters A and D are placed on the glass plate on the riverbank, and B and C are placed on the glass plate in the middle of the river

**Table 1.** Sampling station characteristics

| Sampling station | GPS coordinate | Location | Land use |
|---|---|---|---|
| Station I | 7°47'18.4"S 112°31'14.7"E | Bumiaji, Batu City | Station I is located in the spring area of the Brantas River at an altitude of 1250 meters above sea level. This Station is located in a water resource conservation area in the Brantas River Basin managed by an Indonesian state-owned enterprise. The river water at Station I is clear and odorless, indicating good water quality. The substrate of the riverbed is in the form of rocks and gravel. In the river body, many allocations were found in the form of twigs and leaves from the riverbank. The riverbank plants found in this area include Pinus, cinnamon (*Cinnanonum*), mountain cypress (*Casuarina*), *wedusan* (*Ageratum*), and *tempuyung* (*Sonchus*). |
| Station II | 7°53'52.8"S 112°34'21.8"E | Junrejo, Batu City | Station II is a river fragment that flows through the Sengkaling area, the Dau District, and the Malang District. The environmental hue at Station II is formed by rice fields and tourism, and the river flows pass through the residential area of Batu City. Station II is approximately 10 km to the west of the Malang city center, with an altitude of 600 meters above sea level. The river water at Station II is turbid but odourless, with a riverbed substrate of sand and mud. Many banana tribes (*Musa*), grasses (Poaceae), waru (*Hibiscus*), and pandanus (*Pandanus*) grow on the river banks. |
| Station III | 7°58'46.4"S 112°37'58.6"E | Klojen, Malang City | Station III is a fragment of the river flowing through the bridge on Kahuripan Street in Malang City. This station is located in the center of Malang City at an altitude of 455 m above sea level. Station III is located in a residential area, a home industry, a campus area, and a hospital. The water at this station is used for bathing, washing, and latrines. The river water at Station III is turbid, bubbly, and smelly, with a primary mud substrate. At this station, the river flows with household waste and faeces. Glagah (*Saccharum*) grass grows on the banks. |
| Station IV | 8°00'15.7"S 112°37'59.3"E | Kedungkandang, Malang City | The river of Station IV flows through the Bumiayu Bridge, Malang City, at an altitude of 440 meters above sea level. The environmental hue at Station IV includes residential areas, factories, and agricultural land. The substrates of the riverbed are gravel, sand, and many large stones. This station is located on the outskirts of Malang City, close to the border of the Malang District. Residents utilize this stream channel for domestic purposes, such as bathing and washing. Many plants at this station are dominated by bamboo plants (*Bambusa*) and shrubs, such as *pahitan* (*Tithonia*). |
| Station V | 8°07'31.1"S 112°35'45.4"E | Kepanjen, Malang District | Station V is downstream of the Malang District—the water flow that passes through the Blobo Bridge, Kepanjen District, Malang District. This station is 336 meters above sea level, 18 km south of the Malang city center. The environmental hue of this stream is agricultural land. Station V has a clear water color, with sand and stones as the basic substrate. Plants growing in Station V include lamtoro (*Leucaena*), bamboo (*Bambusa*), and waru (*Hibiscus*). Residents utilize this river flow for bathing, washing, and latrines. |

Each sample was shaken in the laboratory until reaching homogeneity, and 10 mL was collected for purification. Diatom purification was performed in a vaporizer cup by adding potassium permanganate (KMnO4) until it turned purple. Concentrated sulfuric acid (H2SO4) was added until it became clear (Watanabe et al. 1986). Furthermore, the sample was then centrifuged at 2.000 rpm for 15 minutes. A diatom pellet (2 mL) was collected, and distilled water was added to 10 mL. Furthermore, two drops of 40% formalin were added to each well. This precipitate was vortexed till it became homogeneous and collected as a snapshot with a pipette. This substance was dropped onto a fixed Neubauer-type hemocytometer and then observed using an Olympus CX43 trinocular microscope at 400 times magnification. The observation results were identified based on reference literature from the research of Prowse (1962), Yamaji (1962), Watanabe and Usman (1987), Al-Yamani and Saburova (2019), Risjani et al. (2021), and Mahanal and Zubaidah (2023). Finally, the identification results were validated by several microalgae experts at Universitas Negeri Malang.

**Data analysis**

The diatom identification data encompasses three distinct periods: 1998, 2008, and 2023. The data for 1998 and 2008 were obtained from research findings of Mahanal (1998) and Wibowo (2008), while the 2023 data will be directly collected through field research. Each of these years represents the diatom diversity in its respective decade: 1998 for the 1990s, 2008 for the 2000s, and 2023 for the 2020s.

The analysis of diatom diversity involved the calculations of species richness (S), diatom genera density, predominant species, and diversity index (Shannon-

Wiener). The species richness was determined based on the number of species found at each observation station. Predominant species were identified based on the consistency of relative abundance values ≥10% over three replicates. The diatom density was calculated based on the genus level using the following formula:

$$\text{Diatom density} = \frac{n}{p} \times \frac{1000}{90} \quad [1]$$

Where :
n : Number of genera i
p : Number of counts (4 times)

The Shannon-Wiener formula is used by the Diatom Diversity Index (Shannon 1948), which determines the degree of diatom diversity within a population. Diversity is low when the index H' is less than 1, moderate when the index H' is between 1 and 3 (1<H'<3), and high when the index H'≥3:

$$H' = -\Sigma \frac{ni}{N} \ln \frac{ni}{N} \quad [2]$$

Where :
H' : Shannon-Wiener Diversity Index
ni : Number of individuals/species
N : Total number of individuals

One-way ANOVA was used to statistically assess changes in diatom species richness (S) and diversity (Shannon-Wiener) during a three-decade period. Before analysis, the data were examined for homogeneity of variance (using Levene's test) and normality (using the Shapiro-Wilk normality test).

## RESULTS AND DISCUSSION

### Comparison of diatom richness in the Brantas River over three decades

The analysis of literature data identification and expert validation of microalgae in the 2020s decade reveals both differences and similarities compared to the 1990s (Mahanal 1998) and 2000s (Wibowo 2008) (Table 2). Some species were unique to the 2020s, such as *Synedra inaequalis*, *Meridion circulare*, and *Meridion lineare*. In comparison, some others were only found in the 1990s, including *Nitzschia gracilis*, *Nitzschia tenuis*, and *Surirella linearis*). Certain species appeared in the 2020s and 2000s, such as *Fragilaria vaucheriae*, *Navicula cryptotenella*, and *Navicula lanceolata*), while others were identified in the 2020s and 1990s, including *Fragilaria construens* and *Navicula cuspidata*). Furthermore, some other species were found in the 2000s and 1990s decades, consisting of *Eunotia faba*, *Achnanthes acutiuscula*, and *Navicula cincta*). A few species were consistently present across all three decades (e.g., *Coscinodiscus argus*, *Melosira granulata*, and *Synedra ulna*).

The calculation of diatom species richness in the 2020s yielded varying numbers across the observation stations: 45 species at Station I, 53 species at Station II, 28 species at Station III, 34 species at Station IV, and 38 species at Station V. When diatom species richness was compared across the decades—the 1990s (Mahanal 1998), the 2000s (Wibowo 2008), and 2020s—a downward trend was observed at Stations II to V (Figure 2). In contrast, Station I displayed a stable trend in species richness throughout the three decades. These results were reinforced by the one-way ANOVA test, showing significant differences in diatomic species richness between Stations II and V (Station II (0.002), Station III (0.021), Station IV (0.011), and Station V (0.008). However, no significant difference was observed at Station I (0.213), as shown in Table 3.

### Comparison of diatom density of the Brantas River for three decades

The calculation of diatom density from five observation stations during the 2020s showed that the genus *Cocconeis* had the highest density with a value of 149.3 ind./cm$^2$. This pattern is consistent with results from the study in the 1990s (Mahanal 1998) and 2000s (Wibowo 2008), where *Cocconeis* also showed the highest density—221.3 ind./cm$^2$ in the 1990s and 198.7 ind./cm$^2$ in the 2000s. A comparison of genera density values for each decade is shown in Figure 3. In addition, the comparison of diatoms over the three decades showed consistency in the percentage of order levels found in the Brantas River. The order Pennales became the most common diatom taxa found in each year of observation, with an average percentage of±90% (Figure 4).

### Comparison of predominant species of the Brantas River over three decades

The predominant species in the 2020s exhibited different compositions at each observation station. A total of ten species were identified as the predominant species, namely *Achnanthes lanceolata*, *Cocconeis placentula*, *Nitzschia tryblionella* (Station I), *Achnanthes crenulata* and *C. placentula* (Station II), *Eunotia curvata* and *Gomphonema lanceolatum* (Station III), *G. lanceolatum* and *Gomphonema parvulum* (Station IV), and *Navicula rhyncocephala* and *Nitzschia fonticola* (Station V). The number of predominant species in the 2020s differed from that in the 1990s (Mahanal 1998) and the 2000s (Wibowo 2008) (Table 4). The total number of predominant species in the 1990s was seven, and there were nine in the 2000s. The documentation of the predominant species during the three decades of observation under the microscope is depicted in Figure 5.

The predominant species' composition at Station I was consistent over the three decades of observation. More specifically, *A. lanceolata*, *C. placentula*, and *N. tryblionella* were always the predominant species in the 1990s, 2000s, and the 2020s. However, this was not the case at Stations II to V. The predominant species found at Stations II to V showed different compositions in each decade of the study. For example, *Nitzschia microcephala* was the only predominant species in the 1990s, while the predominant species found in the 2000s were *N. microcephala* and *N. cuspidata*. Furthermore, the predominant species found in the 2020s were *G. lanceolatum* and *G. parvulum*.

**Table 2.** Comparison of species found at each observation station over three decades

| Species | Station I | | | Station II | | | Station III | | | Station IV | | | Station V | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 1990s | 2000s | 2020s | 1990s | 2000s | 2020s | 1990s | 2000s | 2020s | 1990s | 2000s | 2020s | 1990s | 2000s | 2020s |
| *Achnanthes crenulata* Grunow, 1860 | ● | ● | ● | ● | ● | ● | ● | - | ● | ● | - | - | ● | ● | ● |
| *Achnanthes hungarica* Grunow, 1860 | ● | ● | ● | ● | ● | ● | ● | - | - | ● | - | - | ● | - | ● |
| *Achnanthes lanceolata* (Brébisson) Grunow, 1860 | ● | ● | ● | ● | - | - | - | - | - | ● | - | - | ● | - | - |
| *Achnanthes acutiuscula* Kützing, 1844 | - | - | - | - | ● | - | - | - | - | - | - | - | - | ● | - |
| *Achnanthes minutissima* Kützing, 1833 | ● | - | - | ● | - | - | - | - | - | ● | - | - | ● | - | - |
| *Achnanthes brevipes* C. Agardh, 1831 | - | - | ● | - | ● | ● | - | - | - | - | - | - | - | - | - |
| *Achnanthes subhudsonis* Hustedt, 1930 | - | - | ● | - | - | ● | - | - | - | - | - | - | - | - | ● |
| *Achnanthes tropica* Hustedt, 1937 | - | - | ● | - | - | ● | - | - | - | - | - | - | - | - | ● |
| *Amphora acutiuscula* Kützing, 1844 | ● | - | - | ● | - | - | - | - | ● | ● | - | ● | ● | - | ● |
| *Amphora bitumida* Prowse, 1967 | - | - | - | ● | ● | - | ● | ● | ● | ● | ● | ● | ● | ● | - |
| *Amphora bullatoides* Hustedt, 1955 | - | - | - | ● | ● | - | - | ● | - | ● | ● | - | - | - | - |
| *Amphora delphinea* Bailey, 1854 | ● | ● | - | ● | ● | - | ● | ● | - | ● | ● | - | ● | ● | - |
| *Amphora holsatica* Hustedt, 1955 | - | ● | - | ● | ● | ● | - | - | ● | ● | ● | - | ● | - | ● |
| *Amphora normanii* Rabenhorst, 1864 | - | - | - | ● | ● | ● | - | ● | - | ● | ● | ● | ● | - | ● |
| *Amphora ovalis* Kützing, 1844 | ● | ● | ● | ● | - | ● | - | ● | - | ● | ● | - | ● | ● | ● |
| *Amphora stigosa* Hustedt 1949 | - | - | ● | ● | - | ● | - | - | - | ● | - | - | ● | - | ● |
| *Amphora proteus* Gregory, 1957 | - | - | - | ● | - | ● | - | - | - | - | ● | - | - | ● | ● |
| *Biddulphia laevis* Ehrenberg, 1844 | ● | - | - | ● | - | ● | - | ● | ● | ● | - | ● | - | ● | - |
| *Caloneis bacillum* (Grunow) Cleve, 1894 | - | ● | ● | ● | ● | - | - | - | - | ● | ● | - | ● | ● | - |
| *Caloneis silicula* (Ehrenberg) Cleve, 1894 | - | - | ● | ● | - | - | ● | - | - | ● | - | - | ● | - | - |
| *Cocconeis pediculus* Ehrenberg, 1838 | ● | ● | ● | ● | ● | ● | - | - | - | ● | ● | - | ● | ● | ● |
| *Cocconeis placentula* Ehrenberg, 1838 | ● | ● | ● | ● | ● | ● | ● | - | - | ● | ● | - | ● | ● | ● |
| *Coscinodiscus argus* Ehrenberg, 1844 | ● | - | ● | ● | ● | ● | ● | - | ● | ● | - | ● | ● | ● | ● |
| *Cymbella microcephala* Grunow, 1862 | ● | ● | ● | - | ● | ● | - | - | - | ● | ● | - | - | - | - |
| *Cymbella ventricosa* C. Agardh, 1830 | ● | ● | ● | ● | - | ● | ● | - | - | ● | ● | - | ● | ● | - |
| *Cymbella tumida* (Brébisson) Van Heurck, 1880 | - | - | ● | ● | ● | - | ● | ● | ● | ● | ● | ● | ● | ● | - |
| *Cymbella turgida* Gregory, 1856 | - | - | - | ● | ● | - | ● | - | - | ● | - | - | ● | - | - |
| *Cymbella kolbei* Hustedt, 1939 | ● | - | - | - | - | - | ● | - | - | ● | - | - | ● | - | - |
| *Cymbella turgidula* Grunow, 1880 | ● | - | ● | ● | - | ● | ● | - | ● | ● | - | ● | ● | - | ● |
| *Diploneis ovalis* (Hilse) Cleve, 1894 | ● | - | - | ● | ● | - | ● | ● | - | ● | ● | - | ● | - | - |
| *Denticula vanheurckii* Grunow, 1880 | - | - | - | - | - | - | - | - | ● | - | - | - | - | - | - |
| *Eunotia trinacria* Ehrenberg, 1843 | - | - | - | - | - | - | - | - | ● | - | - | ● | - | - | - |
| *Eunotia curvata* Ehrenberg, 1837 | - | - | - | - | - | - | - | - | ● | - | - | ● | - | - | - |
| *Eunotia faba* Ehrenberg, 1832 | ● | ● | - | ● | ● | - | ● | ● | - | ● | ● | - | ● | - | - |
| *Eunotia monodon* Ehrenberg, 1832 | ● | ● | - | ● | ● | - | - | ● | - | ● | ● | - | ● | - | - |
| *Fragilaria construens* (Ehrenberg) Grunow, 1862 | ● | - | - | ● | - | - | - | - | - | ● | - | - | - | - | - |
| *Fragilaria crotonensis* Kitton, 1869 | ● | - | - | ● | ● | - | - | - | - | ● | - | - | ● | - | - |
| *Fragilaria vaucheriae* (Kützing) Petersen, 1928 | ● | - | ● | ● | ● | ● | - | - | - | ● | ● | ● | ● | ● | ● |
| *Fragilaria virescens* Ralfs, 1861 | - | - | ● | - | - | ● | ● | - | - | ● | - | - | ● | - | ● |
| *Frustulia rhomboides* (Ehrenberg) De Toni, 1891 | ● | ● | ● | ● | ● | ● | ● | - | ● | ● | ● | - | ● | - | - |
| *Frustulia saxonica* Rabenhorst, 1864 | ● | ● | ● | ● | ● | ● | - | - | - | ● | - | - | ● | ● | - |
| *Frustulia vulgaris* (Thwaites) De Toni, 1891 | ● | ● | ● | ● | ● | ● | ● | - | - | ● | ● | ● | ● | ● | - |
| *Frustulia rhomboides* (Ehrenberg) De Toni, 1891 | ● | ● | ● | ● | ● | ● | - | ● | ● | ● | ● | ● | ● | ● | - |
| *Frustulia saxonica* Rabenhorst, 1864 | ● | ● | - | ● | ● | ● | - | ● | ● | ● | - | ● | ● | ● | ● |
| *Frustulia vulgaris* (Thwaites) De Toni, 1891 | ● | - | - | ● | - | ● | ● | - | - | ● | - | ● | ● | - | ● |
| *Frustulia rhomboides* (Ehrenberg) De Toni, 1891 | ● | ● | - | ● | ● | ● | - | ● | ● | ● | ● | ● | ● | ● | ● |
| *Frustulia saxonica* Rabenhorst, 1864 | ● | ● | - | ● | - | ● | ● | ● | ● | ● | ● | ● | ● | ● | ● |
| *Frustulia vulgaris* (Thwaites) De Toni, 1891 | ● | ● | ● | ● | ● | ● | - | ● | - | ● | ● | ● | ● | ● | ● |
| *Frustulia rhomboides* (Ehrenberg) De Toni, 1891 | - | - | ● | - | - | ● | - | - | ● | - | - | ● | - | - | - |
| *Gyrosigma distortum* (W. Smith) Cleve, 1894 | - | - | - | - | - | - | - | - | ● | - | - | - | - | - | - |
| *Gyrosigma scalproides* (Rabenhorst) Cleve, 1894 | - | - | - | ● | ● | - | - | ● | ● | ● | ● | ● | ● | ● | - |
| *Gyrosigma spenceri* (W. Smith) Cleve, 1894 | - | - | - | ● | ● | - | ● | ● | - | ● | ● | - | ● | - | - |
| *Hantzschia amphioxys* (Ehrenberg) Grunow, 1880 | ● | - | - | ● | ● | - | ● | - | - | ● | ● | - | ● | ● | - |
| *Melosira solida* (Ehrenberg) Kützing, 1844 | - | ● | - | ● | ● | ● | - | - | ● | - | - | - | - | - | ● |
| *Melosira granulata* (Ehrenberg) Ralfs, 1843 | - | - | - | ● | - | ● | ● | ● | ● | ● | ● | ● | ● | - | - |
| *Melosira varians* C. Agardh, 1824 | - | - | - | ● | - | ● | - | - | ● | ● | ● | ● | - | ● | - |
| *Melosira italica (*Ehrenberg) Kützing, 1844 | - | - | ● | ● | - | ● | - | - | ● | - | ● | ● | - | - | ● |
| *Meridion lineare* (C. Agardh) C. Agardh, 1824 | - | - | - | - | - | - | - | - | ● | - | - | ● | - | - | - |
| *Meridion circulare* (Greville) C. Agardh, 1824 | - | - | - | - | - | ● | - | - | ● | - | - | ● | - | - | ● |
| *Navicula bacillum* Ehrenberg, 1843 | ● | - | - | ● | - | - | ● | - | - | ● | ● | - | - | - | - |
| *Navicula lanceolata* (Agardh) Ehrenberg, 1838 | - | ● | - | - | - | - | - | - | - | - | ● | - | - | - | - |
| *Navicula monilifera* Cleve, 1895 | - | ● | - | - | - | - | - | - | - | - | ● | - | - | - | - |
| *Navicula cincta* (Ehrenberg) Ralfs, 1861 | - | ● | - | ● | ● | - | - | ● | - | - | ● | - | - | ● | - |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *Navicula cryptocephala* Kützing, 1844 | ● | ● | - | ● | ● | - | ● | - | - | ● | ● | - | - | ● | - |
| *Navicula cryptotenella* Lange-Bertalot, 1986 | ● | ● | ● | ● | ● | ● | ● | - | - | ● | ● | - | ● | ● | ● |
| *Navicula confervacea* Kützing, 1844 | - | ● | ● | ● | ● | ● | ● | - | - | ● | ● | ● | ● | - | ● |
| *Navicula cuspidata* Kützing, 1844 | - | - | ● | ● | - | ● | - | - | - | - | - | - | - | - | ● |
| *Navicula feuerbornii* Hustedt, 1930 | - | ● | - | ● | ● | - | ● | ● | - | - | ● | - | - | - | - |
| *Navicula pupula* Kützing, 1844 | ● | ● | ● | ● | - | ● | ● | - | - | - | ● | - | - | ● | - |
| *Navicula rhynchocephala* Hustedt, 1930 | - | ● | ● | ● | ● | ● | ● | ● | - | ● | ● | ● | ● | - | ● |
| *Neidium iridis* (Ehrenberg) Cleve, 1894 | - | - | - | ● | - | - | ● | ● | - | - | ● | - | - | - | - |
| *Nitzschia palea* (Kützing) W. Smith, 1853 | - | ● | - | - | ● | - | - | ● | - | - | ● | - | - | ● | - |
| *Nitzschia amphibia* Grunow, 1862 | ● | ● | - | ● | ● | - | ● | ● | - | ● | ● | - | - | - | - |
| *Nitzschia filiformis* (W. Smith) Van Heurck, 1880 | ● | ● | - | ● | ● | - | ● | ● | - | ● | ● | - | ● | ● | - |
| *Nitzschia gandersheimensis* Krasske, 1939 | - | ● | - | ● | ● | - | ● | ● | - | ● | ● | - | - | - | - |
| *Nitzschia microcephala* Grunow, 1862 | - | ● | - | ● | ● | - | ● | ● | - | - | ● | - | - | ● | - |
| *Nitzschia philippinarum* Hustedt, 1937 | ● | ● | - | ● | ● | - | ● | ● | - | ● | ● | - | ● | - | - |
| *Nitzschia fonticola* Grunow, 1862 | ● | ● | - | ● | ● | - | ● | ● | - | ● | ● | - | ● | ● | - |
| *Nitzschia rostellata* Hustedt, 1930 | ● | ● | ● | ● | ● | ● | - | ● | - | ● | ● | ● | ● | ● | ● |
| *Nitzschia philippinarum* Hustedt, 1937 | - | ● | ● | ● | ● | ● | ● | ● | - | ● | ● | ● | - | ● | ● |
| *Nitzschia rompea* Grunow, 1862 | - | ● | - | ● | ● | - | ● | ● | - | ● | ● | - | - | - | - |
| *Nitzschia sigma* (Kützing) W. Smith, 1853 | - | ● | - | ● | ● | - | - | ● | ● | ● | ● | ● | - | - | ● |
| *Nitzschia tryblionella* Hantzsch, 1860 | ● | ● | ● | ● | ● | ● | - | ● | - | ● | ● | ● | ● | ● | - |
| *Nitzschia gracilis* Hantzsch, 1860 | - | - | - | ● | - | - | - | - | - | ● | - | - | ● | - | - |
| *Nitzschia ignorata* Krasske, 1939 | - | - | - | ● | ● | - | - | ● | - | - | ● | - | - | - | - |
| *Nitzschia paradoxa* (Gmelin) Grunow, 1862 | ● | - | - | ● | ● | - | ● | ● | - | ● | - | - | - | - | - |
| *Nitzschia stagnorum* Ehrenberg, 1843 | ● | - | ● | ● | ● | ● | ● | ● | - | - | - | - | - | - | ● |
| *Nitzschia tenuis* Grunow, 1862 | - | - | - | ● | - | - | ● | - | - | ● | - | - | - | - | - |
| *Nitzschia obtusa* W. Smith, 1853 | - | - | - | ● | - | ● | ● | ● | - | ● | ● | - | ● | ● | ● |
| *Pinularia macilenta* (Kützing) Krammer, 1992 | - | - | ● | - | - | ● | ● | - | - | - | - | - | - | - | - |
| *Pinularia microstauron* (Ehrenberg) Cleve, 1894 | ● | ● | ● | ● | ● | ● | ● | - | ● | ● | ● | - | ● | ● | ● |
| *Rhoicosphenia abbreviata* (C. Agardh) Lange-Bertalot, 1980 | - | - | ● | - | - | ● | - | - | - | - | - | - | - | - | - |
| *Surirella robusta* Ehrenberg, 1838 | - | ● | ● | ● | - | ● | ● | - | - | ● | - | - | ● | ● | - |
| *Surirella tenuissima* Hustedt, 1930 | - | ● | - | ● | ● | - | ● | - | - | - | - | - | - | ● | - |
| *Surirella angusta* Kützing, 1844 | - | - | - | ● | - | - | - | - | - | - | ● | - | ● | - | - |
| *Surirella linearis* W. Smith, 1853 | - | - | - | ● | - | - | - | - | - | - | - | - | - | - | - |
| *Stauroneis anceps* Ehrenberg, 1838 | ● | ● | - | ● | ● | - | - | - | - | ● | - | - | - | - | - |
| *Stauroneis pusilla* A. Cleve, 1895 | ● | ● | ● | ● | ● | ● | ● | - | ● | - | ● | ● | - | ● | ● |
| *Stauroneis phoenicenteron* (Nitzsch) Ehrenberg, 1838 | - | ● | ● | ● | ● | ● | ● | - | - | ● | ● | ● | - | - | ● |
| *Stenopterobia intermedia* (Grunow) Lange-Bertalot, 1995 | - | - | ● | - | - | - | - | - | - | - | - | - | - | - | - |
| *Synedra inaequalis* Ehrenberg, 1838 | - | - | ● | - | - | ● | - | - | - | - | - | ● | - | - | - |
| *Synedra ulna* (Nitzsch) Ehrenberg, 1832 | - | ● | ● | ● | ● | ● | ● | ● | - | ● | ● | - | ● | ● | ● |
| *Synedra rumpens* Kützing, 1844 | - | - | ● | ● | ● | ● | ● | ● | - | ● | ● | - | - | ● | ● |

Note: The symbol "●" represents "present" and the symbol "-" represents "absent"

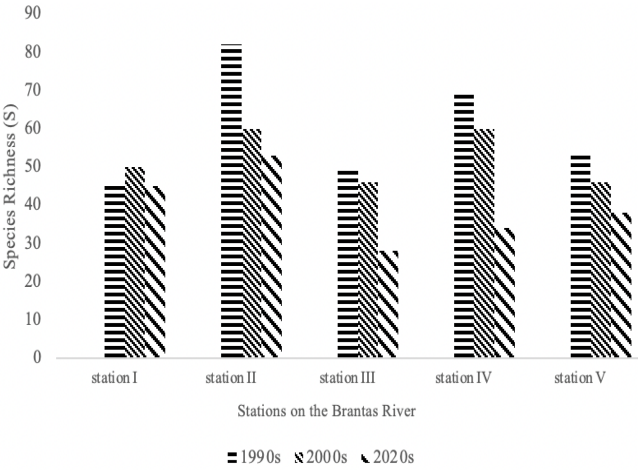


**Figure 2.** Comparison of diatom species richness values at each observation station for three decades

### Comparison of diatom diversity in the Brantas River over three decades

At each observation station, the 2020s Shannon-Wiener diversity index revealed different results. Station II had the highest diversity index (2.59±0.37), followed by Stations I (2.38±0.19), V (2.18±0.09), IV (2.14±0.21), and III (1.98±0.48). When the Shannon-Wiener diversity index was calculated in the 1990s, the results indicated a moderate category. The 2020s saw a different diatom diversity index than the 1990s (Mahanal 1998) and 2000s (Wibowo 2008). The diatom diversity index showed a downward trend at Stations II-V. At Station I, however, the diatom diversity index did not show a declining trend (Figure 6). The findings of the one-way ANOVA test supported this conclusion. The one-way ANOVA test supported this finding by demonstrating that the diatom diversity index changed from Station II to Station V (Table 5). At Station I (0.375), however, the diatom diversity index did not show any variation.

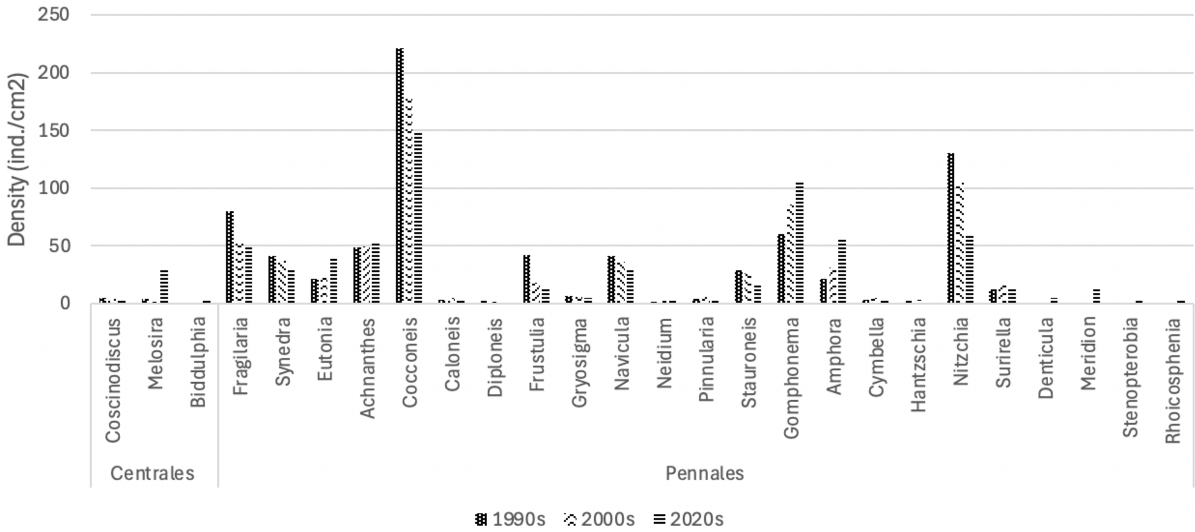


**Figure 3.** Comparison of the mean density of diatom genera found in the Brantas River over three decades

**Table 3.** One-way ANOVA results of diatom species richness at each observation station for three decades

| Station | One-Way ANOVA species richness (S) diatom |
|---|---|
| Station I | 0.213 |
| Station II | 0.002 |
| Station III | 0.021 |
| Station IV | 0.011 |
| Station V | 0.008 |

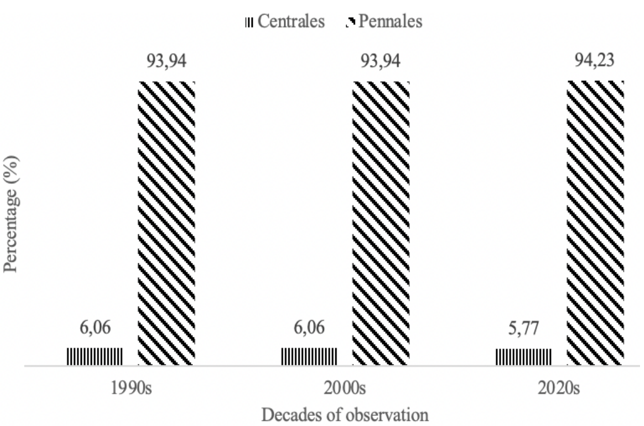


**Figure 4.** Percentage of orders Centrales and Pennales in the Brantas River, Malang, Indonesia, over three decades

## Discussion

Calculation of species richness and diatom diversity index showed the same pattern a downward trend at Stations II to V over the three decades of the study. However, this situation did not occur at Station I. The values of species richness and diversity index at Station I have been relatively the same during the three decades of research. Furthermore, the results of the one-way ANOVA test showed no significant differences in the values of species richness and diatom diversity index at this station. In contrast, significant changes occurred at Stations II-V. The decrease in the species richness and diatom diversity index at Stations II to V was caused by various factors, such as environmental pollution (Zelnik and Sušin 2020) and anthropogenic human activities around the river area (Xu et al. 2022). The downward trend can also indicate a decline in water quality from the 1990s to the 2020s (Passy et al. 2018). Species richness and diversity indices decrease if environmental conditions become polluted (Busseni et al. 2020). This condition differs from that of Station I, which is located in the Brantas River Spring Conservation Area. Such a condition makes the values of species richness and the diatom diversity index relatively the same because of minimal anthropogenic human activities (Shibabaw et al. 2021), natural aquifer systems (Mutinova et al. 2020; Rong et al. 2020), and well-maintained conservation areas (Roestamy and Fulazzaky 2022).

Patterns of decreased diatom diversity due to environmental degradation have also been reported in various other rivers in Indonesia. Soeprobowati et al. (2022) found that epiphytic diatom assemblages in Cebong Lake, Central Java, showed a decline in diversity due to tourism pressure and land use change. Similarly, Supono and Hudaidah (2018) observed a decline in diatom richness and dominance of tolerant species in cultured ponds and connected rivers in Lampung Province, resulting from increased nutrient inputs and sedimentation.

In a study by Sukma and Takarina (2022), diatom diversity in Angke River and Grogol River in Jakarta was affected by water quality and heavy metal concentrations, especially copper (Cu) and lead (Pb). Furthermore, Bramburger et al. (2017) reported that in Lake Matano, Sulawesi, human-induced shoreline modification and increased suspended sediment load (TSS) contributed to a decrease in diatom diversity. These patterns are consistent with the findings of this study, reinforcing the interpretation that anthropogenic activities whether urban, agricultural or industrial play an important role in shaping diatom communities and indicating the health of freshwater ecosystems.

**Table 4.** Comparison of the predominant diatom species at each observation station over the past three decades

| Family | Genus | Species | Station I | | | Station II | | | Station III | | | Station IV | | | Station V | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1990s | 2000s | 2020s | 1990s | 2000s | 2020s | 1990s | 2000s | 2020s | 1990s | 2000s | 2020s | 1990s | 2000s | 2020s |
| Achnantaceae | Achnanthes | *Achnanthes crenulata* Grunow, 1860 | | | | | | ● | | | | | | | | | |
| | | *Achnanthes lanceolata* (Brébisson) Grunow, 1860 | ● | ● | ● | | | | | | | | | | | | |
| | Cocconeis | *Cocconeis placentula* Ehrenberg, 1838 | ● | ● | ● | | ● | ● | | | | | | | | | |
| | | *Cocconeis pediculus* Ehrenberg, 1838 | | | | | | | | | | | | | | ● | |
| Eunotiaceae | Eunotia | *Eunotia curvata* Ehrenberg, 1837 | | | | | | | | | ● | | | | | | |
| Fragillariaceae | Fragilaria | *Fragilaria vaucheriae* (Kützing) Petersen, 1928 | | | | ● | | | | | | | | | | | |
| Naviculaceae | Frustulia | *Frustulia saxonica* Rabenhorst, 1864 | | | | | | | | | | | | | | ● | |
| | Navicula | *Navicula cuspidata* Kützing, 1844 | | | | | | | | | | | ● | | | | |
| | | *Navicula rhynchocephala* Hustedt, 1930 | | | | | | | | | | | | | | | ● |
| Gomphonemaceae | Gomphonema | *Gomphonema lanceolatum* Ehrenberg, 1838 | | | | | | | | ● | ● | | | ● | | | |
| | | *Gomphonema parvulum* Kützing, 1849 | | | | | | | | | | | | ● | | | |
| Nitzchiaceae | Nitzschia | *Nitzschia fonticola* Grunow, 1862 | | | | | | | | | | | | | | | ● |
| | | *Nitzschia tryblionella* Hantzsch, 1860 | ● | ● | ● | | | | | | | | | | ● | | |
| | | *Nitzschia palea* (Kützing) W. Smith, 1853 | | | | | ● | | ● | ● | | | | | | | |
| | | *Nitzschia obtusa* W. Smith, 1853 | | | | | | | ● | | ● | | | | | | |
| | | *Nitzschia microcephala* Grunow, 1862 | | | | | | | | | | ● | ● | | | | |

Note: The symbol ● is the predominant identified

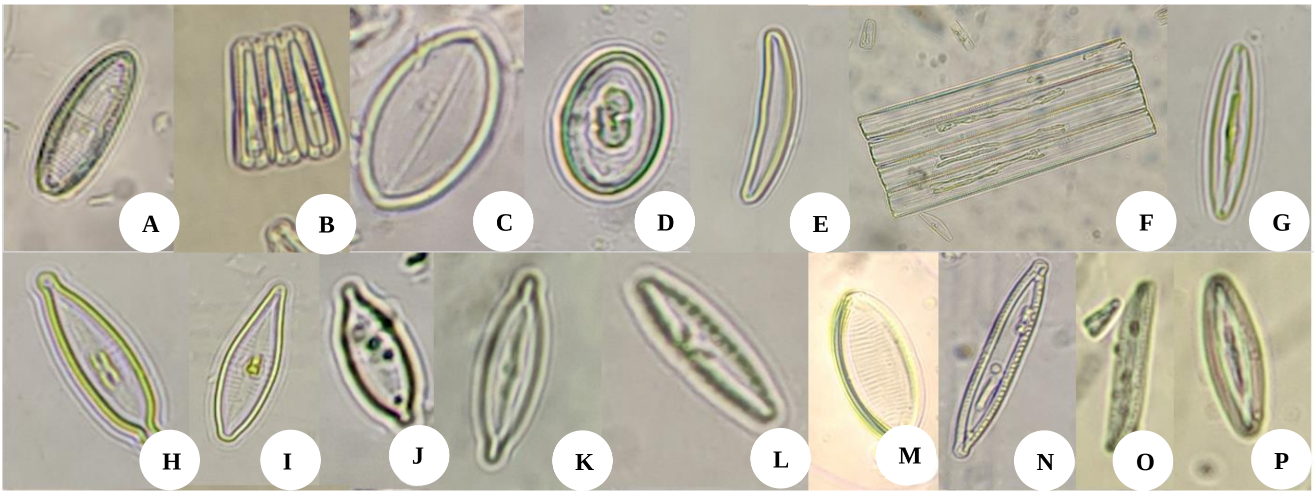


**Figure 5.** Documentation of predominant species over three decades of observation using a 400 times magnification ocular microscope. A. *Achnanthes crenulata*; B. *Achnanthes lanceolata*; C. *Cocconeis placentula*; D. *Cocconeis pediculus*; E. *Eunotia curvata*; F. *Fragilaria vaucherias*; G. *Frustulia saxonica*; H. *Gomphonema lanceolatum*; I. *Gomphonema parvulum*; J. *Navicula cuspidata*; K. *Navicula rhyncocephala*; L. *Nitzschia fonticola*; M. *Nitzschia tryblionella*; N. *Nitzschia palea*; O. *Nitzschia obtusa*; P. *Nitzschia microcephala*

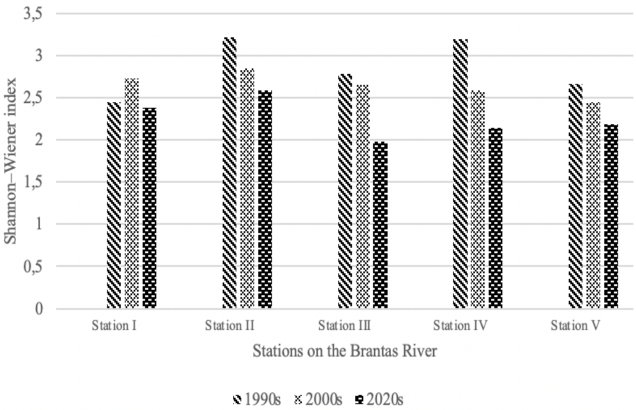


**Figure 6.** Comparison of the diatom diversity index at each station over three decades

**Table 5.** One-way ANOVA results of the diatom diversity index at each observation station for three decades

| Station | One-Way ANOVA |
|---|---|
| Station I | 0.375 |
| Station II | 0.011 |
| Station III | 0.019 |
| Station IV | 0.000 |
| Station V | 0.004 |

Pennales became the most common order in the Brantas River during three decades of observation. The diatom in the order was always found to be as high as ±93% during the three decades of observation. At the same time, the Centrales order was only found at ±4% during the three decades of observation. The order Pennales can be found because it is a typical environmental niche (Risjani et al. 2021). In addition, most orders of Pennales live as periphyton organisms (Lebkuecher et al. 2023), which have a good ability to attach to substrates since they have crystalloid organelles and fibrils that produce mucous organelles (mucus) or chitin (Nassiri et al. 1998; Camps et al. 2021). These organelles are not found in the order Centrales (Zhang et al. 2008). Therefore, most Centrales are planktonic rather than periphytonic (Nonoyama et al. 2019).

*Cocconeis* is the most common genus found in the Brantas River every decade. *Cocconeis* is abundant because the habitat of the genus is in relatively calm waters (Huang et al. 2019; Sullivan 2019), such as in observation stations located in rivers with relatively slow current. In addition, the large number of *Cocconeis* genera is also due to the physicochemical conditions in the Brantas River flow, supporting the development of this genus (Yan et al. 2018). Each diatom genus has a different tolerance to aquatic environmental conditions (Xu et al. 2022; Sevindik et al. 2023). These environmental conditions include physicochemical levels, nutrients, and geographical conditions (Chen et al. 2019; Orefice et al. 2019; Kong et al. 2021; Shibabaw et al. 2021).

The predominant species found at Stations II to V showed different results over the three decades of study, while the predominant species at Station I showed the same results during the three decades of research. This situation is probably due to the changes in water conditions at Stations II to V during each decade of observation. Predominant species are diatom species with the highest number of individuals and are dominant in a population (Cantonati et al. 2020; Heramza et al. 2021). Predominant species can be used as bioindicators of water quality (Pandey et al. 2018). Furthermore, each predominant species has a different range of adaptation to abiotic environmental factors (Cantonati et al. 2022; Komala et al.

2023). Based on this tolerance range, each predominant species tends to exhibit different population abundances in its abiotic environment (Bailet et al. 2019; Medeiros et al. 2020; Solak et al. 2020). Changes in abiotic environmental conditions at Stations II to V led to changes in the predominant species in each decade of observation (Elshobary et al. 2020; Taxböck et al. 2020).

In conclusion, comparing species richness and diversity index values over three decades showed a downward trend at Stations II-V. The downward trend in the values of species richness and diatom diversity index is thought to be related to a decrease in water quality at each observation station, while the values of species richness and diversity index at Station I tended to be relatively the same for the three decades. The species richness and diversity index values were relatively the same at Station I, presumably because the water quality was still relatively the same. At the order level, Pennales is consistently the most common order found in every decade of observation, with a percentage of ±93%. At the genus level, *Cocconeis* was consistently the most common genus found in every decade of observation. Observations of the predominant species at the Station I consistently showed the same results over the three decades of observation. The predominant species at Station I were *A. lanceolata*, *C. placentula*, and *N. tryblionella*. Observations of the predominant species at Stations II to V showed different compositional changes during each decade of observation. This study has limitations because it did not measure physicochemicals at each observation station, so it cannot confirm the condition of the water quality of the Brantas River at each observation station. Therefore, the results of the current study recommend that further research be conducted focusing on the distribution of diatom communities based on physicochemistry in the Brantas River area, Malang. The results of these studies are expected to confirm the potential of diatom data as an indicator of the water quality of the Brantas River.

## ACKNOWLEDGEMENTS

We would like to thank the Directorate General of Higher Education, Ministry of Education and Culture of the Republic of Indonesia for funding assistance through the Masters Education Towards Doctorate for Excellent Graduates (PMDSU) program with contract number: 0667/E5/AL.04/2024.

## REFERENCES


Al-Yamani F, Saburova MA. 2019. Marine Phytoplankton of Kuwait's Waters. Volume II Diatoms. Cyanobacteria, Dinoflagellates, Flagellates. Kuwait Institute For Scientific Research, Kuwait.

Arsad S, Putra KT, Latifah N, Kadim MK, Musa M. 2021. Epiphytic microalgae community as aquatic bioindicator in Brantas River, East Java, Indonesia. Biodiversitas 22 (7): 2961-2971. DOI: 10.13057/biodiv/d220749.

Bach LT, Taucher J. 2019. $CO_2$ effects on diatoms: A synthesis of more than a decade of ocean acidification experiments with natural communities. Ocean Sci 15 (4): 1159-1175. DOI: 10.5194/os-15-1159-2019.

Bailet B, Bouchez A, Franc A, Frigerio J-M, Keck F, Karjalainen S-M, Rimet F, Schneider S, Kahlert M. 2019. Molecular versus morphological data for benthic diatoms biomonitoring in Northern Europe freshwater and consequences for ecological status. Metabarcoding Metagenom 3: e34002. DOI: 10.3897/mbmg.3.34002.

Basuki TM, Indrawati DR, Nugroho HYSH et al. 2024. Water pollution of some major rivers in Indonesia: The status, institution, regulation, and recommendation for its mitigation. Pol J Environ Stud 33 (4): 3515-3530. DOI: 10.15244/pjoes/178532.

Batubara B, Kooy M, Van Leynseele Y, Zwarteveen M, Ujianto A. 2023. Urbanization in (post-) New Order Indonesia: Connecting unevenness in the city with that in the countryside. J Peasant Stud 50 (3): 1207-1226. DOI: 10.1080/03066150.2021.2000399.

B-Béres V, Stenger-Kovács C, Buczkó K, Padisák J, Selmeczy GB, Lengyel E, Tapolczai K. 2023. Ecosystem services provided by freshwater and marine diatoms. Hydrobiologia 850 : 2707-2733. DOI: 10.1007/s10750-022-04984-9.

Bramburger AJ, Hamilton PB, Haffner GD. 2017. Effects of long-term anthropogenic disturbance on the benthic episammic diatom community of an ancient, tropical lake. Bull Environ Contam Toxicol 99 (5): 542-547. DOI: 10.1007/s00128-017-2181-8.

Busseni G, Caputi L, Piredda R et al. 2020. Large scale patterns of marine diatom richness: Drivers and trends in a changing ocean. Glob Ecol Biogeogr 29 (11): 1915-1928. DOI: 10.1111/geb.13161.

Camps GA, Cosacov A, Sérsic AN. 2021. Centre-periphery approaches based on geography, ecology and historical climate stability: What explains the variation in morphological traits of *Bulnesia sarmientoi*? Ann Bot 127 (7): 943-955. DOI: 10.1093/aob/mcab034.

Cantonati M, Hofmann G, Spitale D, Werum M, Lange-Bertalot H. 2022. Diatom red lists: Important tools to assess and preserve biodiversity and habitats in the face of direct impacts and environmental change. Biodivers Conserv 31: 453-477. DOI: 10.1007/s10531-021-02339-9.

Cantonati M, Kelly MG, Demartini D, Angeli N, Dörflinger G, Papatheodoulou A, Armanini DG. 2020. Overwhelming role of hydrology-related variables and river types in driving diatom species distribution and community assemblage in streams in Cyprus. Ecol Indic 117: 106690. DOI: 10.1016/j.ecolind.2020.106690.

Chen S, Zhang W, Zhang J, Jeppesen E, Liu Z, Kociolek JP, Xu X, Wang L. 2019. Local habitat heterogeneity determines the differences in benthic diatom metacommunities between different urban river types. Sci Total Environ 669: 711-720. DOI: 10.1016/j.scitotenv.2019.03.030.

Costa APT, Schneck F. 2022. Diatoms as indicators in running waters: Trends of studies on biological assessment and monitoring. Environ Monit Assess 194 (10): 695. DOI: 10.1007/s10661-022-10383-3.

Coste M, Boutry S, Tison-Rosebery J, Delmas F. 2009. Improvements of the Biological Diatom Index (BDI): Description and efficiency of the new version (BDI-2006). Ecol Indic 9 (4): 621-650. DOI: 10.1016/j.ecolind.2008.06.003.

Elshobary ME, Essa DI, Attiah AM, Salem ZE, Qi X. 2020. Algal community and pollution indicators for the assessment of water quality of Ismailia Canal, Egypt. Stoch Environ Res Risk Assess 34: 1089-1103. DOI: 10.1007/s00477-020-01809-w.

Falasco E, Ector L, Wetzel CE, Badino G, Bona F. 2021. Looking back, looking forward: A review of the new literature on diatom teratological forms (2010-2020). Hydrobiologia 848: 1675-1753. DOI: 10.1007/s10750-021-04540-x.

Hagan JG, Vanschoenwinkel B, Gamfeldt L. 2021. We should not necessarily expect positive relationships between biodiversity and ecosystem functioning in observational field data. Ecol Lett 24 (12): 2537-2548. DOI: 10.1111/ele.13874.

Hasan V, Andraini NE, Isroni W et al. 2023. Fish diversity of the Bengawan Solo River estuary, East Java, Indonesia. Biodiversitas 24 (4): 2207-2216. DOI: 10.13057/biodiv/d240433.

Hayati A, Tiantono N, Mirza MF et al. 2017. Water quality and fish diversity in the Brantas River, East Java, Indonesia. J Biol Res 22 (2): 43-49. DOI: 10.23869/bphjbr.22.2.20172.

Heikkinen JM, Aalto J, Rantamäki O, Ruikkala T, Soininen J, Pajunen V. 2022. Observing diatom diversity and community composition along environmental gradients in subarctic mountain ponds. Freshw Biol 67 (4): 731-741. DOI: 10.1111/fwb.13877.

Heramza K, Barour C, Djabourabi A, Khati W, Bouallag C. 2021. Environmental parameters and diversity of diatoms in the Aïn Dalia

dam, Northeast of Algeria. Biodiversitas 22 (9): 3633-3644. DOI: 10.13057/biodiv/d220901.
Huang CX, Dong HC, Lundholm N, Teng ST, Zheng GC, Tan ZJ, Lim PT, Li Y. 2019. Species composition and toxicity of the genus *Pseudo-nitzschia* in Taiwan Strait, including *P. chiniana* sp. nov. and *P. qiana* sp. nov. Harmful Algae 84: 195-209. DOI: 10.1016/j.hal.2019.04.003.
Ismanto A, Hadibarata T, Kristanti RA, Maslukah L, Safinatunnajah N, Sathishkumar P. 2022. The abundance of Endocrine-Disrupting Chemicals (EDCs) in downstream of the Bengawan Solo and Brantas Rivers located in Indonesia. Chemosphere 297: 134151. DOI: 10.1016/j.chemosphere.2022.134151.
Januar HI, Pujiono E, Sutomo et al. 2025. Geospatial Mapping of River Health Assessment: A Study Case of Spatial and Seasonal Monitoring at Sumbawa Island Watersheds, Indonesia. In Remotely Sensed Rivers in the Age of Anthropocene (pp. 483-503). Cham, Springer Nature Switzerland. DOI: 10.1007/978-3-031-82311-4_19.
Khumairoh U, Teixeira HM, Yadav S et al. 2024. Linking types of East Javanese rice farming systems to farmers' perceptions of complex rice systems. Agric Syst 218: 104008. DOI: 10.1016/j.agsy.2024.104008.
Kock A, Glanville HC, Law AC, Stanton T, Carter LJ, Taylor JC. 2023. Emerging challenges of the impacts of pharmaceuticals on aquatic ecosystems: A diatom perspective. Sci Total Environ 878: 162939. DOI: 10.1016/j.scitotenv.2023.162939.
Komala PS, Silvia S, Windi S. 2023. Phytoplankton dynamics and its relation to physicochemical parameters in the dry season of Maninjau Lake, West Sumatra, Indonesia. J Ecol Eng 24 (9): 218-231. DOI: 10.12911/22998993/169233.
Kong X, Seewald M, Dadi T, Friese K, Mi C, Boehrer B, Schultze M, Rinke K, Shatwell T. 2021. Unravelling winter diatom blooms in temperate lakes using high frequency data and ecological modeling. Water Res 190: 116681. DOI: 10.1016/j.watres.2020.116681.
Lebkuecher JG, Atma JL, Conn H, Redwine DJ. 2023. Composition of epilithic diatom and soft-algal assemblages in infralittoral zones of Tennessee reservoirs and correlations of composition to trophic state. J Freshw Ecol 38 (1): 2182836. DOI: 10.1080/02705060.2023.2182836.
Luethje M, Snyder J. 2021. Climate-related morphological changes in *Pantocsekiella* (Mediophyceae) spanning 0-1.2 Ma in Lake El'gygytgyn, northeastern Russia including *Pantocsekiella elgygytgynensis* sp. *nov*. Phytotaxa 478 (1): 67-91. DOI: 10.11646/phytotaxa.478.1.5.
Mahanal S, Zubaidah S. 2023. Diatoms in the Brantas River. CV. Global Aksara Pers, Surabaya. [Indonesian]
Mahanal S. 1998. Periphyton Diatoms as Biological Indicators of River Water Quality Study in Kali Brantas River. [Thesis]. Universitas Negeri Malang, Malang. [Indonesian]
Masithah ED, Islamy RA. 2023. Checklist of freshwater periphytic diatoms in the midstream of Brantas River, East Java, Indonesia. Biodiversitas 24 (6): 3269-3281. DOI: 10.13057/biodiv/d240621.
Masouras A, Karaouzas I, Dimitriou E, Tsirtsis G, Smeti E. 2021. Benthic diatoms in river biomonitoring—present and future perspectives within the water framework directive. Water 13 (4): 478. DOI: 10.3390/w13040478.
Mbao EO, Odinga ES, Nyika J, Ochieng B, Kitaka N. 2022. A bibliometric study on the use of diatoms in water quality monitoring and bioassessment in Africa across 10-year (2012-2022) period. Aquat Sci 84 (4): 58. DOI: 10.1007/s00027-022-00891-2.
Medeiros G, Padial AA, Amaral MWW, Ludwig TAV, Bueno NC. 2020. Environmental variables likely influence the periphytic diatom community in a subtropical lotic environment. Limnologica 80: 125718. DOI: 10.1016/j.limno.2019.125718.
Minaoui F, Hakkoum Z, Douma M, Mouhri K, Loudiki M. 2021. Diatom communities as bioindicators of human disturbances on suburban soil quality in arid Marrakesh area (Morocco). Water Air Soil Pollut 232: 146. DOI: 10.1007/s11270-021-05094-3.
Mutinova PT, Kahlert M, Kupilas B, McKie BG, Friberg N, Burdon FJ. 2020. Benthic diatom communities in urban streams and the role of riparian buffers. Water 12 (10): 2799. DOI: 10.3390/w12102799.
Nassiri Y, Robert J-M, Rincé Y, Ginsburger-Vogel T. 1998. The cytoplasmic fine structure of the diatom *Haslea ostrearia* (Bacillariophyceae) in relation to marennine production. Phycologia 37 (2): 84-91. DOI: 10.2216/i0031-8884-37-2-84.1.
Nohe A, Goffin A, Tyberghein L, Lagring R, De Cauwer K, Vyverman W, Sabbe K. 2020. Marked changes in diatom and dinoflagellate biomass, composition and seasonality in the Belgian Part of the North Sea between the 1970s and 2000s. Sci Total Environ 716: 136316. DOI: 10.1016/j.scitotenv.2019.136316.
Nonoyama T, Kazamia E, Nawaly H, Gao X, Tsuji Y, Matsuda Y, Bowler C, Tanaka T, Dorrell RG. 2019. Metabolic innovations underpinning the origin and diversification of the diatom chloroplast. Biomolecules 9 (8): 322. DOI: 10.3390/biom9080322.
Orefice I, Musella M, Smerilli A, Sansone C, Chandrasekaran R, Corato F, Brunet C. 2019. Role of nutrient concentrations and water movement on diatom's productivity in culture. Sci Rep 9: 1479. DOI: 10.1038/s41598-018-37611-6.
Pandey LK, Lavoie I, Morin S, Park J, Lyu J, Choi S, Lee H, Han T. 2018. River water quality assessment based on a multi-descriptor approach including chemistry, diatom assemblage structure, and non-taxonomical diatom metrics. Ecol Indic 84: 140-151. DOI: 10.1016/j.ecolind.2017.07.043.
Parmar TK, Rawtani D, Agrawal YK. 2016. Bioindicators: The natural indicator of environmental pollution. Front Life Science 9 (2): 110-118. DOI: 10.1080/21553769.2016.1162753.
Passy SI, Larson CA, Jamoneau A, Budnick W, Heino J, Leboucher T, Tison-Rosebery J, Soininen J. 2018. Biogeographical patterns of species richness and abundance distribution in stream diatoms are driven by climate and water chemistry. Am Nat 192 (5): 605-617. DOI: 10.1086/699830.
Prasertsin T, Suk-Ueng K, Phinyo K, Yana E. 2021. The diversity and abundance of phytoplankton and benthic diatoms in varying environmental conditions in Kok River, Chiang Rai, Thailand as bio-indicators of water quality. Biodiversitas 22 (4): 1853-1862. DOI: 10.13057/biodiv/d220431.
Prowse EW. 1962. Diatoms of Malayan Freshwaters. Gardens' Bulletin, Singapore.
Remondi F, Burlando P, Vollmer D. 2016. Exploring the hydrological impact of increasing urbanisation on a tropical river catchment of the metropolitan Jakarta, Indonesia. Sustainable Cities and Society 20: 210-221. DOI: 10.1016/j.scs.2015.10.001.
Risjani Y, Witkowski A, Kryk A et al. 2021. Indonesian coral reef habitats reveal exceptionally high species richness and biodiversity of diatom assemblages. Estuar Coast Shelf Sci 261: 107551. DOI: 10.1016/j.ecss.2021.107551.
Rodríguez-Miret X, del Carmen Trapote M, Sigró J, Vegas-Vilarrúbia T. 2023. Diatom responses to warming, heavy rains and human impact in a Mediterranean lake since the preindustrial period. Sci Total Environ 884: 163685. DOI: 10.1016/j.scitotenv.2023.163685.
Roestamy M, Fulazzaky MA. 2022. A review of the water resources management for the Brantas River basin: Challenges in the transition to an integrated water resources management. Environ Dev Sustain 24: 11514-11529. DOI: 10.1007/s10668-021-01933-9.
Rong X, Qian W, Mingxiang Z, Wenbin P, Jim WJ. 2020. Plankton distribution patterns and the relationship with environmental gradients and hydrological connectivity of wetlands in the Yellow River Delta. Ecohydrol Hydrobiol 20 (4): 584-596. DOI: 10.1016/j.ecohyd.2020.01.002.
Salim W, Hudalah D. 2020. Urban governance challenges and reforms in Indonesia: towards a new Urban Agenda. In: Dahiya B, Das A (eds). New Urban Agenda in Asia-Pacific. Advances in 21st Century Human Settlements. Springer, Singapore. DOI: 10.1007/978-981-13-6709-0_6.
Sevindik TO, Kinali ZD, Tunca H. 2023. Temporal and spatial changes in diatom community structure with the effects of environmental parameters, and ecological status assessment by diatom indices in three shallow lakes (Sakarya, Turkey). Biologia 78: 373-387. DOI: 10.1007/s11756-022-01220-6.
Shannon CE. 1948. A mathematical theory of communication. Bell Syst Tech J 27 (3): 379-423. DOI: 10.1002/j.1538-7305.1948.tb01338.x.
Shibabaw T, Beyene A, Awoke A, Tirfie M, Azage M, Triest L. 2021. Diatom community structure in relation to environmental factors in human influenced rivers and streams in tropical Africa. PLoS One 16 (2): e0246043. DOI: 10.1371/journal.pone.0246043.
Soeprobowati TR, Purnaweni H, Jumari J, Sari K. 2022. The relationship of water quality to epipelic diatom assemblages in Cebong Lake, Dieng Indonesia. Pol J Environ Stud 31 (1): 281-295. DOI: 10.15244/pjoes/137084.
Solak CN, Peszek Ł, Yilmaz E, Ergül HA, Kayal M, Ekmekçi F, Várbíró G, Yüce AM, Canli O, Binici MS, Ács É. 2020. Use of diatoms in monitoring the Sakarya river basin, Turkey. Water 12 (3): 703. DOI: 10.3390/w12030703.
Sukma AM, Takarina ND. 2022. Relationship of diatom phytoplankton (Bacillariophyceae) diversity with water quality and heavy metal in

Angke and Grogol Rivers, Jakarta City. IOP Conf Ser: Earth Environ Sci 1083: 012071. DOI: 10.1088/1755-1315/1083/1/012071.

Sullivan T. 2019. Cell shape and surface colonisation in the diatom genus *Cocconeis*—An opportunity to explore bio-inspired shape packing? Biomimetics 4 (2): 29. DOI: 10.3390/biomimetics4020029.

Supono S, Hudaidah S. 2018. Short Communication: The diversity of epipelic diatoms as an indicator of shrimp pond environmental quality in Lampung Province, Indonesia. Biodiversitas 19 (4): 1220-1226. DOI: 10.13057/biodiv/d190406.

Taxböck L, Karger DN, Kessler M, Spitale D, Cantonati M. 2020. Diatom species richness in Swiss springs increases with habitat complexity and elevation. Water 12 (2): 449. DOI: 10.3390/w12020449.

Topal E, Rajendran H, Zgłobicka I, Gluch J, Liao Z, Clausner A, Jan Kurzydłowski K, Zschech E. 2020. Numerical and experimental study of the mechanical response of diatom frustules. Nanomaterials 10 (5): 959. DOI: 10.3390/nano10050959.

Valen FS, Soemarno, Widodo MS, Wiadnya DGR, Hasan V. 2020. Contemporary distribution records of yellow finned Barb *Mystacoleucus marginatus* (Valenciennes, 1842) in Brantas Basin, Indonesia. Ecol Environ Conserv 26: S40-S43.

Virta L, Teittinen A. 2022. Threshold effects of climate change on benthic diatom communities: Evaluating impacts of salinity and wind disturbance on functional traits and benthic biomass. Sci Total Environ 826: 154130. DOI: 10.1016/j.scitotenv.2022.154130.

Watanabe T, Asai K, Houki A. 1986. Saprophilous and eurysaprobic diatom taxa to organic water pollution and diatom assemblage index (DAIpo). Diatom 2: 23-73.

Watanabe T, Usman R. 1987. Epilithic fresh-water diatoms in Central Sumatra. Diatom: Japan J Diatomol 3: 33-87.

Wibowo ALP. 2008. Detection of Brantas River Quality with Biological Indicators (in Brantas River, Malang). [Thesis]. Universitas Negeri Malang, Malang. [Indonesian]

Widodo MS, Hasan V, Mukti AT, Kusuma B. 2020. Distribution of Dwarf Snakehead *Channa gachua* Hamilton, 1822 (Teleostei, Channidae) on Brantas River Basin, Indonesia. Ecol Environ Conserv 26 (2): 618-621.

Wiwoho BS, Phinn S, McIntyre N. 2023. Characterizing watersheds to support land-use planning in Indonesia: A case study of Brantas tropical watershed. Ecohydrol Hydrobiol 23 (4): 635-649. DOI: 10.1016/j.ecohyd.2023.06.001.

Xu M, Wang R, Dong X, Zhang Q, Yang X. 2022. Intensive human impacts drive the declines in heterogeneity of diatom communities in shallow lakes of East China. Ecol Indic 140: 108994. DOI: 10.1016/j.ecolind.2022.108994.

Yamaji I. 1962. The Plankton of Japanese Coastal Waters. Hoiku-sha, Osaka, Japan. [Japanese]

Yan Y, Wang L, Li J, Li J, Zou Y, Zhang J, Li P, Liu Y, Xu B, Gu Z, Wan X. 2018. Diatom response to climatic warming over the last 200 years: A record from Gonghai Lake, North China. Palaeogeogr Palaeoclimatol Palaeoecol 495: 48-59. DOI: 10.1016/j.palaeo.2017.12.023.

Zelnik I, Sušin T. 2020. Epilithic diatom community shows a higher vulnerability of the river Sava to pollution during the winter. Diversity 12 (12): 465. DOI: 10.3390/d12120465.

Zhang Y, Tao J, Wang J, Ding L, Ding C, Li Y, Zhou Q, Li D, Zhang H. 2019. Trends in diatom research since 1991 based on topic modeling. Microorganisms 7 (8): 213. DOI: 10.3390/microorganisms7080213.

Zhang Z, Zhou R, Tang T, Huang Y, Zhong Y, Shi S. 2008. Genetic variation in central and peripheral populations of *Excoecaria agallocha* from Indo-West Pacific. Aquat Bot 89 (1): 57-62. DOI: 10.1016/j.aquabot.2008.03.002.