



Integrated Correlation Analysis of Phytoplankton Community Structure and Physicochemical Parameters for Water Quality Assessment in Ranu Grati, Indonesia

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ABSTRACT

Purpose of the study: This study aimed to analyze the relationship between phytoplankton abundance and physicochemical parameters in the waters of Ranu Grati and to evaluate the water quality status based on Government Regulation of the Republic of Indonesia Number 22 of 2021.

Methodology: This study employed a descriptive quantitative method using field observation and laboratory analysis. Water samples were collected from several sampling stations in Ranu Grati. Physicochemical parameters were measured using a thermometer, Secchi disk, pH meter, DO meter, and spectrophotometer. Phytoplankton identification was conducted microscopically using an Olympus binocular microscope, while correlation analysis was performed using Microsoft Excel and SPSS software.

Main Findings: A total of 18 phytoplankton genera belonging to six divisions were identified in the waters of Ranu Grati. Temperature, pH, dissolved oxygen, and total nitrogen met the Class III water quality standards, whereas transparency, BOD, COD, and total phosphate exceeded the permissible limits. Correlation analysis revealed that transparency, dissolved oxygen, BOD, COD, total nitrogen, and total phosphate strongly influenced phytoplankton abundance and distribution patterns.

Novelty/Originality of this study: This study provides updated scientific information regarding the ecological relationship between phytoplankton communities and physicochemical parameters in Ranu Grati waters using correlation-based analysis integrated with national water quality standards. The findings contribute to the development of ecological monitoring data and provide a scientific basis for sustainable lake management and aquatic ecosystem conservation in tropical inland waters.

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1. INTRODUCTION

Phytoplankton are microscopic organisms that drift in aquatic environments and function as primary producers within aquatic ecosystems. These organisms perform photosynthesis and support food chains and ecosystem stability in freshwater environments [1]-[3]. The presence of phytoplankton is widely used as a

biological indicator of water quality conditions [4]-[6]. Changes in physical and chemical water parameters can rapidly influence phytoplankton community structures [7]-[9]. Therefore, studies concerning phytoplankton are essential for evaluating ecological conditions in aquatic ecosystems.

Water quality is strongly influenced by human activities occurring around aquatic environments. Domestic activities, agriculture, and aquaculture practices can significantly increase water pollution levels [10]-[12]. The accumulation of organic waste and aquaculture residues may alter the physical and chemical characteristics of water bodies [13], [14]. These environmental changes directly affect the distribution and abundance of aquatic organisms, including phytoplankton [15]-[17]. Consequently, phytoplankton are considered effective bioindicators for detecting environmental changes in aquatic ecosystems.

Lakes are freshwater ecosystems that provide important ecological and socio-economic functions for surrounding communities. Lakes serve as habitats for aquatic organisms, water resources, tourism destinations, and aquaculture areas [18]-[20]. The existence of lakes also contributes to environmental balance within surrounding regions [21]-[23]. However, excessive utilization of lake resources may lead to environmental degradation and declining water quality [24], [25]. Therefore, sustainable management and monitoring of lake ecosystems are urgently needed.

Ranu Grati is a volcanic lake located in Pasuruan Regency, East Java, which is utilized for various community activities. The lake area is surrounded by settlements, agricultural lands, and floating net cage aquaculture activities [26], [27]. These activities potentially increase organic waste inputs and reduce overall water quality conditions [28], [29]. Declining water quality may affect aquatic organisms, particularly phytoplankton that are sensitive to environmental changes [30], [31]. Therefore, research concerning phytoplankton conditions in Ranu Grati is important to conduct.

Several previous studies have examined the relationship between water quality and phytoplankton communities in aquatic ecosystems. Research by Sawestri & Herlan [1], demonstrated that phytoplankton respond rapidly to environmental changes and can function as aquatic bioindicators. Another study by Esteban et al. [33] explained that temperature, pH, and dissolved oxygen significantly influence phytoplankton community structures. Meanwhile, in Ranu Grati only focused on the relationship between nitrogen and phosphorus ratios and phytoplankton abundance. Previous studies have not comprehensively integrated diversity, abundance, and physicochemical correlation analyses in Ranu Grati waters.

The novelty of this study lies in its comprehensive analysis of phytoplankton diversity and abundance associated with physicochemical parameters in Ranu Grati waters. This study not only identifies phytoplankton genera but also examines ecological relationships between water quality and phytoplankton communities. The measured parameters include temperature, pH, dissolved oxygen, biological oxygen demand, chemical oxygen demand, total nitrogen, and phosphate. In addition, this study applies correlation analysis to determine environmental influences on phytoplankton abundance. This integrated approach provides more comprehensive ecological information compared with previous studies.

This research is important because lake water quality continues to experience pressure from human activities surrounding the Ranu Grati area. Information regarding phytoplankton diversity and abundance is needed to support sustainable lake management and conservation efforts. Furthermore, this study may serve as a scientific reference for evaluating water quality using natural bioindicators. The findings are expected to provide scientific data regarding the relationship between water quality and phytoplankton communities in Ranu Grati waters. Therefore, this study aims to analyze phytoplankton diversity, abundance, and the relationship between physicochemical parameters and phytoplankton communities in Ranu Grati waters.

2. RESEARCH METHOD

2.1. Research Design

This study employed a quantitative descriptive approach to analyze the diversity and abundance of phytoplankton in Ranu Grati waters, Pasuruan Regency, East Java. The study also examined the relationship between phytoplankton communities and physicochemical water parameters. Sampling was conducted using a purposive sampling method based on environmental characteristics and surrounding human activities. Observations focused on phytoplankton diversity, abundance, dominance, and water quality conditions. Correlation analysis was performed to determine the relationship between physicochemical parameters and phytoplankton abundance.

2.2. Time and Study Area

The research was conducted from November 2023 to January 2024 in Ranu Grati, Pasuruan Regency, East Java, Indonesia. The study area consisted of five observation stations representing different environmental conditions and anthropogenic activities around the lake. The selected stations included areas near settlements, agricultural activities, floating net cages, tourism activities, and relatively undisturbed zones. Sampling locations

were determined based on accessibility and ecological characteristics of the waters. Laboratory analyses were conducted after field sampling activities were completed.

2.3. Tools and Materials

The tools used in this study included a plankton net, sample bottles, microscope, Sedgwick-Rafter counting chamber, thermometer, Secchi disk, pH meter, dissolved oxygen meter, and laboratory equipment for physicochemical analyses. Water samples were collected using sterile sampling bottles. Phytoplankton samples were preserved using Lugol solution before laboratory identification. The materials analyzed included phytoplankton samples and water samples from each observation station. Supporting software, including PAST version 4.03, was used for diversity analysis.

2.4. Sampling Procedure

Water and phytoplankton samples were collected at five observation stations with three replications at each station. Phytoplankton samples were obtained by filtering water using a plankton net and transferring the concentrate into sample bottles. Samples were preserved immediately using Lugol solution to maintain organism integrity during storage and transportation. Water samples for physicochemical analyses were collected simultaneously from the same stations. All samples were labeled according to station and replication number before laboratory analysis.

2.5. Phytoplankton Identification and Analysis

Phytoplankton identification was conducted morphologically under a microscope up to the genus level. Identification referred to phytoplankton classification guides and relevant taxonomic references. Diversity analysis was calculated using the Shannon-Wiener diversity index. Phytoplankton abundance was determined using the APHA method and expressed as individuals per liter (Ind/L). Dominance index analysis was performed to determine dominant genera within the phytoplankton community.

2.6. Physicochemical Parameters

The measured physicochemical parameters included temperature, transparency, pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen, and phosphate. Temperature, transparency, pH, and dissolved oxygen were measured directly in the field. Biological oxygen demand, chemical oxygen demand, total nitrogen, and phosphate were analyzed in the laboratory. Water quality evaluation referred to the Indonesian Government Regulation standards concerning water quality management. All measurements were conducted in triplicate to ensure data reliability.

2.7. Data Analysis

Phytoplankton diversity was analyzed using the Shannon-Wiener diversity index, while abundance analysis followed the APHA calculation method. Dominance analysis used Simpson's dominance index to determine the dominance level of particular genera. Descriptive analysis was used to present phytoplankton composition and physicochemical conditions at each station. Correlation analysis was applied to determine the relationship between physicochemical parameters and phytoplankton abundance. The results were presented in tables and graphs to facilitate interpretation of ecological conditions in Ranu Grati waters.

3. RESULTS AND DISCUSSION

3.1. Phytoplankton Genera in the Waters of Ranu Grati

The phytoplankton identified in the waters of Ranu Grati consisted of 18 genera, namely *Euglena*, *Cocconeis*, *Trachelomonas*, *Microcystis*, *Monoraphidium*, *Peridium*, *Phacus*, *Navicula*, *Synedra*, *Cryptomonas*, *Pinnularia*, *Oocystis*, *Kirchneriella*, *Coscinodiscus*, *Dinobryon*, *Cymbella*, *Ulothrix*, and *Closterium*. The identification results based on the characteristics of each phytoplankton genus are described as follows:

Specimen 1: Genus *Euglena*

Based on observations conducted under a magnification of 25×10, Specimen 1 exhibited several distinctive morphological characteristics. The specimen appeared elongated or oval-shaped with slightly pointed ends. Its body shape may vary depending on environmental conditions and physiological activity. The organism consisted of a cell body equipped with a flagellum at the anterior end. The cell body was green due to the presence of chlorophyll pigments, while the flagellum functioned as a locomotory organ. The cells generally appeared bright green because of the abundance of chloroplasts. Based on these morphological characteristics, the observed specimen was identified as belonging to the genus *Euglena*.

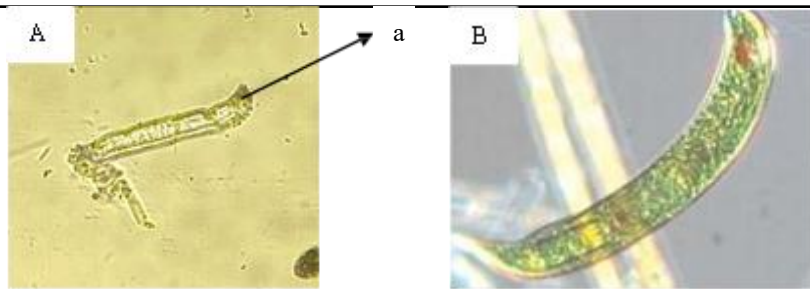


Figure 1. Specimen 1 *Euglena*: observation result (A) and literature reference (B) (Vuurent *et al.* [34]).
a. Flagellum

Euglena is a eukaryotic organism possessing a well-defined nuclear membrane. Members of the genus *Euglena* are commonly found in freshwater environments such as ponds, rivers, and swamps. *Euglena* is capable of surviving in various aquatic conditions, including polluted environments. Generally, *Euglena* consists of a single cylindrical or tubular cell equipped with a flagellum that functions in movement and swimming in water (indicated by arrow a). The flagella in *Euglena* are typically paired and whip-like in structure.

The green coloration of *Euglena* is produced by chlorophyll *a* and *b*, which are involved in the process of photosynthesis. *Euglena* also possesses a structure known as a stigma or eyespot that functions similarly to an “eye,” enabling the organism to detect and move toward light sources. The movement of *Euglena* is commonly referred to as “metakinesis,” involving changes in body shape during locomotion. The classification of *Euglena* according to Leya [35] is as follows:

Kingdom : Excavata
Division : Euglenophyta
Class : Euglenophyceae
Order : Euglenales
Family : Euglenaceae
Genus : *Euglena*

Specimen 2: Genus *Cocconeis*

Observations of Specimen 2 under a magnification of 25×10 revealed several distinctive morphological characteristics. The specimen possessed valves that were elliptical to nearly circular in shape. The observed organism was generally unicellular, although some species may also form colonies. Under closer magnification, fine striae composed of small areolae could be observed. Based on these morphological characteristics, Specimen 2 was identified as belonging to the genus *Cocconeis*.

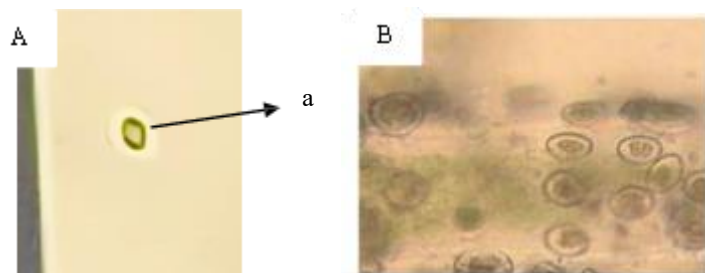


Figure 2. Specimen 2 *Cocconeis*: observation result (A) and literature reference (B) (Vuurent *et al.*, [35]).
a. Frustule

Cocconeis sp. is a diatom genus that may occur either as unicellular organisms or colonies. It is characterized by relatively rapid growth compared with other diatoms, microscopic size, and an epiphytic lifestyle attached to substrates such as macroalgae and aquatic plants. The cells are adnate and attached by mucilaginous valve pads. This diatom genus possesses a frustule with an oval-elliptical shape (indicated by arrow a). *Cocconeis* is commonly found in mesotrophic to eutrophic waters and can survive across a wide range of pH conditions and trophic levels.

The classification of *Cocconeis* according to Taylor and Cocquyt [36] is as follows:

Division : Bacillariophyta
Class : Bacillariophyceae
Order : Bacillariales
Family : Achnantheaceae
Genus : *Cocconeis*

Specimen 3: Genus *Trachelomonas*

Observations of Specimen 3 under a magnification of 25×10 revealed several morphological features characteristic of this genus. The specimen exhibited a round to oval body shape with a reddish-brown coloration. In addition to chlorophyll pigments used for photosynthesis, the presence of carotenoid pigments contributed to body colors ranging from red, orange, to yellow. Careful magnification also revealed the presence of flagella that assisted in locomotion. Based on these morphological characteristics, Specimen 3 was identified as belonging to the genus *Trachelomonas*.

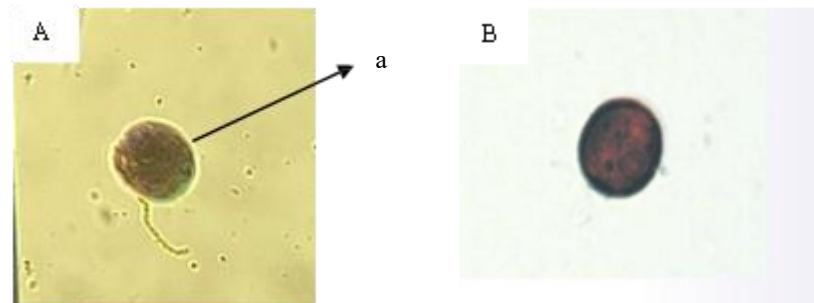


Figure 3. Specimen 3 *Trachelomonas*: observation result (A) and literature reference (B) (Vuurent *et al.*, [35]).
a. Siliceous cell wall

Trachelomonas is a eukaryotic protist genus belonging to the group of flagellated algae inhabiting freshwater environments. Members of this genus are unicellular organisms with cylindrical, tubular, or oval body forms. The body of *Trachelomonas* contains food vacuoles that function in capturing and digesting microscopic food particles such as bacteria, algae, and other small organisms. The cell wall of *Trachelomonas* (indicated by arrow a) is composed of silica or other resistant materials that provide additional protection against environmental conditions and predators. The classification of *Trachelomonas* is as follows:

Kingdom : Protozoa
Phylum : Euglenozoa
Class : Euglenoideae
Order : Euglenida
Family : Euglenaceae
Genus : *Trachelomonas*

Specimen 4: Genus *Microcystis*

Observations of Specimen 4 under a magnification of 25×10 revealed morphological characteristics typical of this genus. The specimen exhibited a spherical shape and consisted of unicellular organisms. Similar to algae in general, the cells appeared green due to the presence of chlorophyll pigments used in photosynthesis. Based on these morphological characteristics, Specimen 4 was identified as belonging to the genus *Microcystis*.

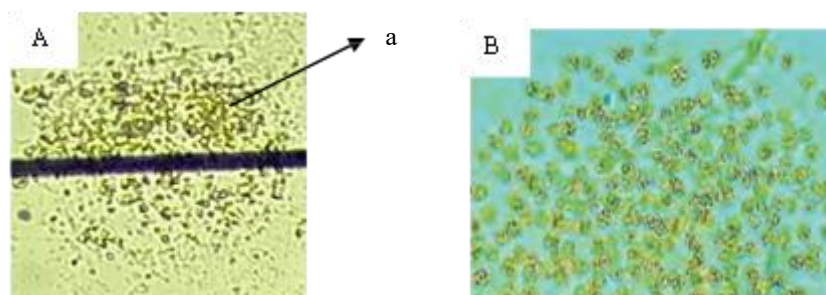


Figure 4. Specimen 4 *Microcystis*: observation result (A) and literature reference (B)
a. Specimen colony

Microcystis belongs to the group of blue-green algae (Cyanobacteria) commonly found in freshwater ecosystems worldwide. Members of this genus are unicellular organisms in which each individual consists of a single cell. The shape of *Microcystis* is generally round to spherical, although it may vary among species. The cell diameter ranges from approximately $2\text{--}7\ \mu\text{m}$. These cells typically form colonies (indicated by arrow a) with diameters ranging from $40\ \mu\text{m}$ to $3\ \text{mm}$ [37].

The green coloration of *Microcystis* results from the presence of chlorophyll pigments, and the cells possess gas vesicles that regulate buoyancy within the water column. *Microcystis* is frequently associated with algal blooms occurring in both freshwater and marine environments.

The classification of *Microcystis* is as follows:

Kingdom : Bacteria
 Phylum : Cyanobacteria
 Class : Cyanophyceae
 Order : Chroococcales
 Family : Microcystaceae
 Genus : *Microcystis*

Specimen 5: Genus *Monoraphidium*

Observations of Specimen 5 under a magnification of 25×10 revealed several characteristic morphological features. The specimen exhibited a curved or spiral form with pointed needle-like ends. It possessed a relatively thin cell wall and contained a single chloroplast filling the cell. Based on these morphological characteristics, Specimen 5 was identified as belonging to the genus *Monoraphidium*.

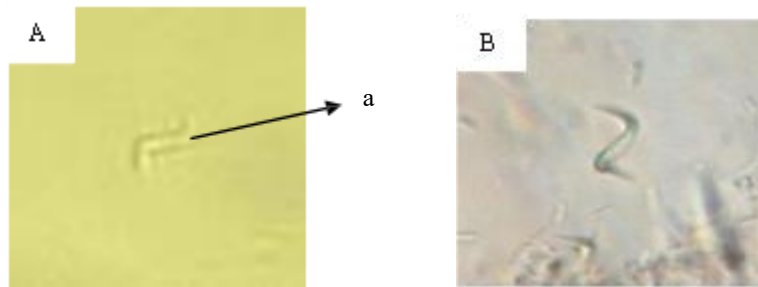


Figure 5. Specimen 5 *Monoraphidium*: observation result (A) and literature reference (B) (Vuurent *et al.*,[35]).
 a. Cell wall

Monoraphidium is a microalgal genus capable of living within a pH range of 5–10. This genus consists of unicellular green algae characterized by thin cell walls (indicated by arrow a) and chlorophyll pigments, although pyrenoids are absent. Pyrenoids are chloroplast structures functioning in food reserve storage. *Monoraphidium* is capable of producing 4–8 autospores after the parent cell wall divides into two parts. The classification of *Monoraphidium* is as follows:

Kingdom : Plantae
 Phylum : Chlorophyta
 Class : Chlorophyceae
 Order : Sphaeropleales
 Family : Selenastraceae
 Genus : *Monoraphidium*

Specimen 6: Genus *Peridinium*

Observations of Specimen 6 under a magnification of 25×10 revealed several distinctive morphological characteristics. The specimen exhibited a spherical unicellular form. The cell was protected by a membrane or covering that functioned as a shell, separating the cell contents from the external environment. Based on these morphological characteristics, Specimen 6 was identified as belonging to the genus *Peridinium*.

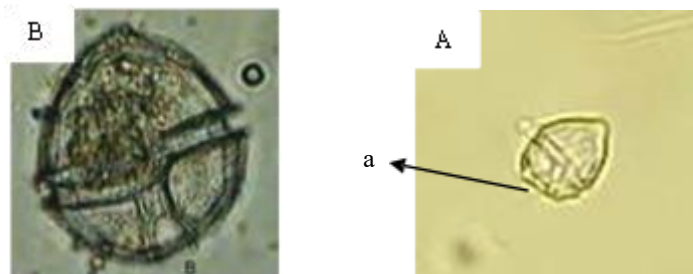


Figure 6. Specimen 6 *Peridinium*: observation result (A) and literature reference (B). a. Cell covering

Peridinium is a genus of unicellular algae belonging to the dinoflagellate group. Generally, *Peridinium* species possess round to oval cells with coloration varying from green to yellow or brown, and cell diameters ranging from approximately 0.01 mm to more than 0.1 mm. Some species are equipped with two flagella used for locomotion.

Most *Peridinium* species possess a cell covering (indicated by arrow a) composed of membranes surrounding the cell. This covering often has projections or spines that give the cells a serrated appearance. The body of *Peridinium* is also equipped with contractile vacuoles that function in regulating osmotic pressure within the cell [35]. Similar to other dinoflagellates, *Peridinium* plays an important role in oxygen production and serves as a fundamental component of aquatic food chains. The classification of *Peridinium* is as follows:

- Kingdom : Protozoa
- Phylum : Myzozoa
- Class : Dinophyceae
- Order : Peridinales
- Family : Peridineaceae
- Genus : *Peridinium*

Specimen 7: Genus *Phacus*

Observations of Specimen 7 under a magnification of 25×10 revealed several distinctive morphological characteristics. The specimen exhibited an oval to slightly rounded cell shape. The cell appeared triangular with one end equipped with a flagellum used for locomotion. The specimen was green in color due to the presence of chlorophyll pigments involved in photosynthesis. Based on these morphological characteristics, Specimen 7 was identified as belonging to the genus *Phacus*.

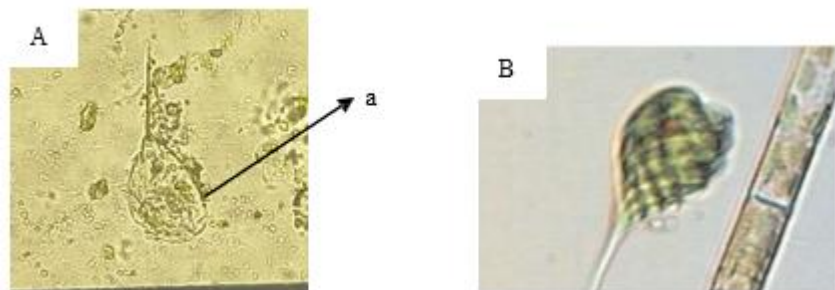


Figure 7. Specimen 7 *Phacus*: observation result (A) and literature reference (B). a. Cell wall

Phacus is a unicellular organism belonging to the protist group. The body shape of *Phacus* is generally triangular, although variations may occur among species and individuals. The chlorophyll pigments present in *Phacus* include chlorophyll *a* and *b*, resulting in its green coloration. Similar to *Euglena*, the genus *Phacus* possesses a contractile vacuole that functions in regulating osmotic pressure within the cell. However, *Phacus* differs from *Euglena* in having a more rigid body shape, typically oval or rounded (indicated by arrow a), whereas *Euglena* exhibits a more flexible and elongated body form. *Phacus* is considered strictly autotrophic, while *Euglena* may also exhibit heterotrophic nutrition under low-light conditions. The classification of *Phacus* is as follows:

- Kingdom : Excavata
- Division : Euglenophyta
- Class : Euglenophyceae
- Order : Euglenales
- Family : Euglenaceae
- Genus : *Phacus*

Specimen 8: Genus *Navicula*

Observations of Specimen 8 under a magnification of 25×10 revealed several morphological characteristics. The specimen possessed highly variable valve shapes and appeared elongated, resembling a boat. The specimen exhibited a yellowish-brown coloration. Based on these observed characteristics, Specimen 8 was identified as belonging to the genus *Navicula*.

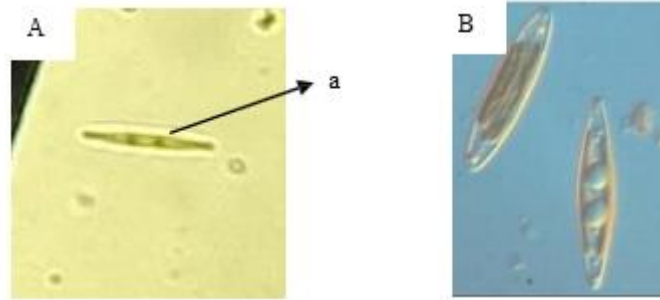


Figure 8. Specimen 8 *Navicula*: observation result (A) and literature reference (B).
a. Siliceous cell wall

Navicula is a unicellular alga with a silica-based cell wall that resembles glass (indicated by arrow a). It is an aquatic organism attached to substrates and can be found in various aquatic environments ranging from marine to freshwater ecosystems. *Navicula* contains plastids with chlorophyll *a*, chlorophyll *c*, and fucoxanthin pigments, which contribute to its brownish coloration. Reproduction primarily occurs through asexual cell division. The classification of *Navicula* is as follows:

Kingdom : Chromista
Phylum : Ochrophyta
Class : Bacillariophyceae
Order : Naviculales
Family : Naviculaceae
Genus : *Navicula*

Specimen 9: Genus *Synedra*

Observations of Specimen 9 under a magnification of 25×10 revealed several characteristic morphological features. The specimen appeared elongated and straight, resembling a pencil, with slightly curved ends. The organism may occur in colonies, although unicellular forms are also present. Its coloration ranged from yellowish-brown to green. Based on these observed characteristics, Specimen 9 was identified as belonging to the genus *Synedra*.

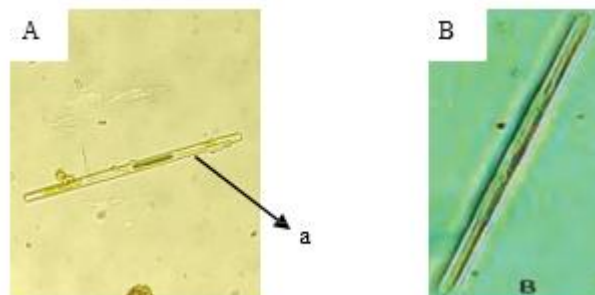


Figure 9. Specimen 9 *Synedra*: observation result (A) and literature reference (B).
a. Cell covering

Synedra belongs to the diatom group characterized by elongated body forms. It may exist as free-floating planktonic organisms or attached to substrates by mucilage. *Synedra* occurs as solitary cells, epiphytic forms attached to surfaces, or colonies inhabiting freshwater ecosystems. The genus possesses layered cell coverings (indicated by arrow a), which contribute to its resistance against environmental changes. The classification of *Synedra* is as follows:

Kingdom : Plantae
Division : Thallophyta
Class : Bacillariophyceae
Order : Pennales
Family : Fragilariaceae
Genus : *Synedra*

Specimen 10: Genus *Cryptomonas*

Observations of Specimen 10 under a magnification of 25×10 revealed several morphological characteristics. The specimen appeared round to elliptical with a dorsiventrally flattened body, slightly concave

on the ventral side and convex on the dorsal side. The specimen exhibited brown to yellowish-green coloration. Based on these characteristics, Specimen 10 was identified as belonging to the genus *Cryptomonas*.

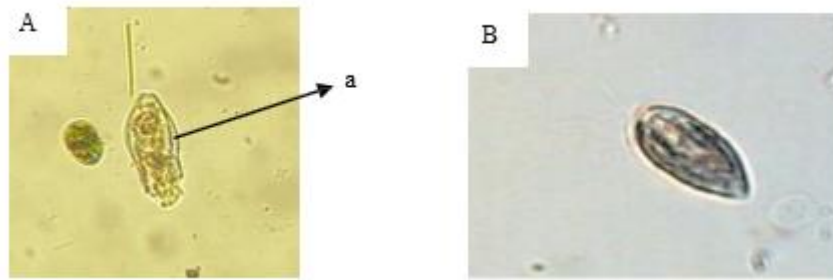


Figure 10. Specimen 10 *Cryptomonas*: observation result (A) and literature reference (B).
a. Chloroplast.

Cryptomonas is a phytoplankton genus characterized by flattened elliptical cells and a unicellular free-living lifestyle, primarily inhabiting freshwater environments. The cells contain two chloroplasts (indicated by arrow a), which may possess pyrenoids. *Cryptomonas* generally exhibits green to yellowish-green coloration. This genus acquires secondary photosynthetic capability through the consumption and retention of red algae. The classification of *Cryptomonas* is as follows:

Kingdom : Chromista
Division : Cryptophyta
Class : Cryptophyceae
Order : Cryptomonadales
Family : Cryptomonadaceae
Genus : *Cryptomonas*

Specimen 11: Genus *Pinnularia*

Observations of Specimen 11 under a magnification of 25×10 revealed several morphological characteristics. The specimen exhibited elongated elliptical cells with rounded ends and a golden-yellow coloration. The organism was unicellular and possessed a central nodule. Based on these observed characteristics, Specimen 11 was identified as belonging to the genus *Pinnularia*.

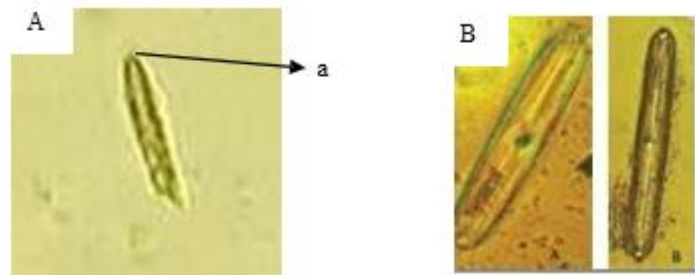


Figure 11. Specimen 11 *Pinnularia*: observation result (A) and literature reference (B). a. Cell wall at the tip

Pinnularia is a unicellular organism with linear, elliptical, or lanceolate cell forms. The body possesses two chloroplast regions, and the cell ends are usually rounded, forming a rosette-like appearance (indicated by arrow a). The cell wall consists of pectic substances within a rigid silica framework. *Pinnularia* can inhabit waters ranging from nutrient-poor to nutrient-rich conditions. The genus is characterized by a golden-brown coloration, and the inner cell wall lacks septa. The classification of *Pinnularia* is as follows:

Kingdom : Protista
Division : Chrysophyta
Class : Bacillariophyceae
Order : Pennales
Family : Naviculoideae
Genus : *Pinnularia*

Specimen 12: Genus *Oocystis*

Observations of Specimen 12 under a magnification of 25×10 revealed several morphological characteristics. The specimen exhibited an oval or egg-shaped body, green coloration, and a unicellular structure.

The cell wall appeared relatively thin. Based on these observed characteristics, Specimen 12 was identified as belonging to the genus *Oocystis*.

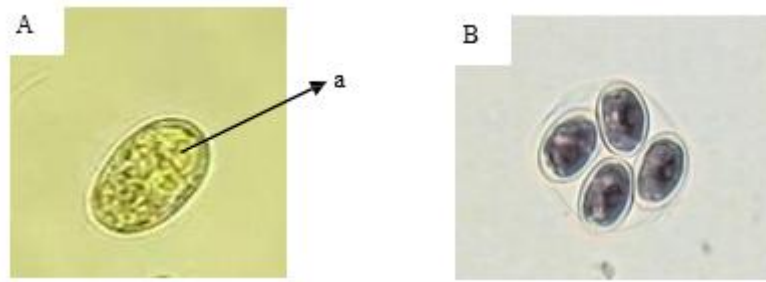


Figure 12. Specimen 12 *Oocystis*: observation result (A) and literature reference (B). a. Openings within the nucleus

Oocystis is a microalgal genus that may occur as solitary cells or colonies enclosed within a parent cell wall. The cells are generally spherical or elliptical and possess large or small openings (indicated by arrow a). The nucleus is centrally located, and the cell wall consists of parallel-arranged microfibril layers. The classification of *Oocystis* is as follows:

Division : Chlorophyta
 Class : Trebouxiophyceae
 Order : Chlorellales
 Family : Oocystaceae
 Genus : *Oocystis*

Specimen 13: Genus *Kirchneriella*

Observations of Specimen 13 under a magnification of 25×10 revealed several distinctive morphological characteristics. The specimen appeared highly curved, with the cell ends nearly touching each other. The organism was unicellular, although colonial forms may also occur, and exhibited a yellowish-green coloration. Based on these characteristics, Specimen 13 was identified as belonging to the genus *Kirchneriella*.



Figure 13. Specimen 13 *Kirchneriella*: observation result (A) and literature reference (B). a. Nearly rounded cell ends

Kirchneriella is a phytoplankton genus that commonly forms colonies with spherical, oval, or irregular shapes surrounded by mucilaginous sheaths. The cells are crescent-shaped or strongly curved, with rounded ends that nearly meet each other (indicated by arrow a), and possess smooth cell walls. Each cell contains chloroplasts with pyrenoids. The classification of *Kirchneriella* is as follows:

Kingdom : Plantae
 Division : Chlorophyta
 Class : Chlorophyceae
 Order : Sphaeropleales
 Family : Selenastraceae
 Genus : *Kirchneriella*

Specimen 14: Genus *Coscinodiscus*

Observations of Specimen 14 under a magnification of 25×10 revealed several morphological characteristics. The specimen exhibited a perfectly circular body shape with green to brownish coloration. Based on the observed characteristics, Specimen 14 was identified as belonging to the genus *Coscinodiscus*.

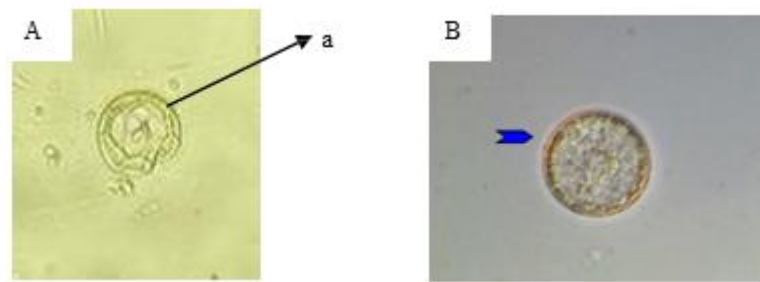


Figure 14. Specimen 14 *Coscinodiscus*: observation result (A) and literature reference (B). a. Cell body with protective cyst

Coscinodiscus is a phytoplankton genus capable of surviving in polluted environments due to the presence of protective cysts that protect the organism from toxic substances. The genus possesses a circular body shape with concentric ring-like structures (indicated by arrow a), brownish coloration, and unicellular organization. The circular body resembles a disc with flat valves. The classification of *Coscinodiscus* is as follows:

Kingdom : Chromista
 Division : Heterokontophyta
 Class : Bacillariophyceae
 Order : Coscinodiscales
 Family : Coscinodiscaceae
 Genus : *Coscinodiscus*

Specimen 15: Genus *Dinobryon*

Observations of Specimen 15 under a magnification of 25×10 revealed several characteristic morphological features. The specimen formed chain-like colonies and exhibited a golden-yellow coloration. The organism may be considered unicellular within colonial structures. Based on these observed characteristics, Specimen 15 was identified as belonging to the genus *Dinobryon*.

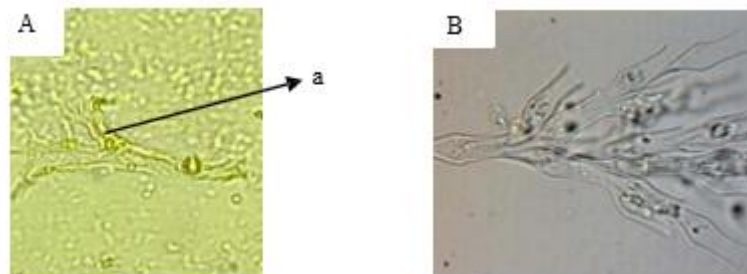


Figure 15. Specimen 15 *Dinobryon*: observation result (A) and literature reference (B). a. Chain-shaped cell body

Dinobryon is a phytoplankton genus characterized by elongated cells attached in chain-like arrangements (indicated by arrow a). Colony formation occurs due to the presence of several lorica structures within the cells, resulting in branched colonial chains. Colonies may contain up to 50 cells, and each cell possesses one or two lateral chloroplasts. The classification of *Dinobryon* is as follows:

Kingdom : Chromista
 Division : Ochrophyta
 Class : Chrysophyceae
 Order : Chromulinales
 Family : Dinobryaceae
 Genus : *Dinobryon*

Specimen 16: Genus *Cymbella*

Observations of Specimen 16 under a magnification of 25×10 revealed several distinctive morphological characteristics. The specimen exhibited a greenish-brown to brown coloration with an elongated asymmetrical or curved body shape and occurred as unicellular forms. Based on these observed characteristics, Specimen 16 was identified as belonging to the genus *Cymbella*.

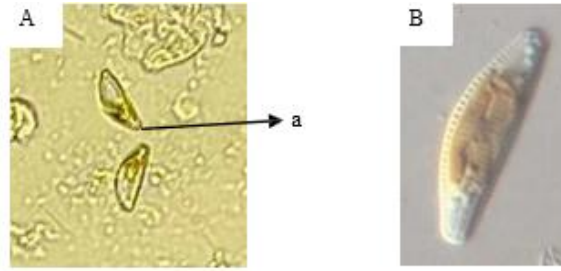


Figure 16. Specimen 16 *Cymbella*: observation result (A) and literature reference (B).
a. Dorsiventral valve

Cymbella is a phytoplankton genus characterized by curved or crescent-shaped body forms. The genus possesses dorsiventral valves with rounded ends (indicated by arrow a). The cells contain single, large, or lobed chloroplasts with central pyrenoids. The classification of *Cymbella* is as follows:

Kingdom : Protista
Phylum : Chrysophyta
Class : Bacillariophyceae
Order : Pennales
Family : Cymbellaceae
Genus : *Cymbella*

Specimen 17: Genus *Ulothrix*

Observations of Specimen 17 under a magnification of 25×10 revealed several characteristic morphological features. The specimen possessed a long cylindrical filamentous body that was unbranched, with green to yellow coloration. The specimen exhibited thick cell walls, although thinner walls may also occur.

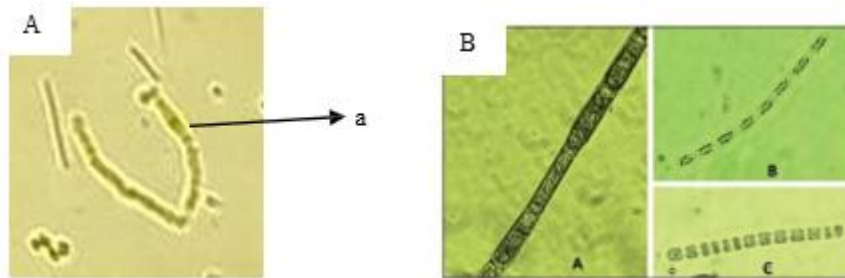


Figure 17. Specimen 17 *Ulothrix*: observation result (A) and literature reference (B).
a. Cylindrical body shape

Ulothrix is an alga characterized by filamentous body forms composed of elongated cylindrical cells (indicated by arrow a). This genus exhibits considerable diversity, including unicellular, colonial, and multicellular forms, and contains chlorophyll pigments along with carotenoids. The cells are unbranched and cylindrical in shape, with parietal chloroplasts. The classification of *Ulothrix* is as follows:

- Kingdom : Protista
- Division : Chlorophyta
- Class : Chlorophyceae
- Order : Ulotrichales
- Family : Ulotrichaceae
- Genus : *Ulothrix*

Specimen 18: Genus *Closterium*

Observations of Specimen 18 under a magnification of 25×10 revealed several morphological characteristics. The specimen exhibited a curved green body and occurred as a single cell. Both ends of the body gradually narrowed and became pointed. Based on these morphological characteristics, Specimen 18 was identified as belonging to the genus *Closterium*.

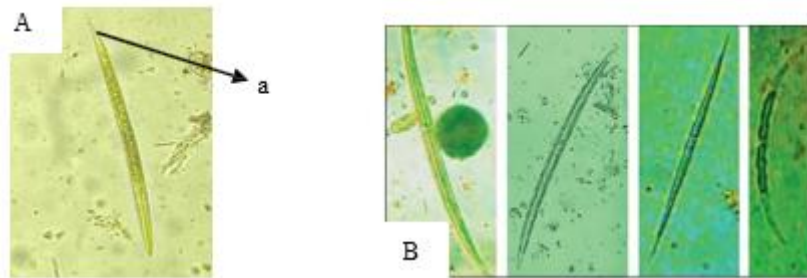


Figure 18. Specimen 18 *Closterium*: observation result (A) and literature reference (B).
a. Pointed cell ends

Closterium belongs to the green algae group within the phylum Chlorophyta. The genus possesses a unique cell shape characterized by cylindrical or tubular forms with pointed ends (indicated by arrow a). Variations in cell morphology may range from relatively straight to curved forms. *Closterium* is commonly found in freshwater habitats, and its mobility is limited because it generally lacks flagella or similar locomotory structures. Movement primarily depends on water currents and passive displacement. The classification of *Closterium* is as follows:

- Kingdom : Protista
- Division : Chlorophyta
- Class : Zygnemophyceae
- Order : Desmidiales
- Family : Closteriaceae
- Genus : *Closterium*

Tabel 1. Hasil identifikasi fitoplankton di perairan Ranu Grati

Class	Order	Family	Genus	
Euglenophyceae	Euglenales	Euglenaceae	<i>Euglena</i>	
			<i>Phacus</i>	
Bacillariophyceae	Bacillariales	Achnanthaceae	<i>Cocconeis</i>	
	Naviculales	Naviculaceae	<i>Navicula</i>	
	Coscinodiscales	Coscinodiscaceae	<i>Coscinodiscus</i>	
		Pennales	Fragilariaceae	<i>Synedra</i>
	Euglenoideae	Euglenida	Naviculoideae	<i>Pinnularia</i>
			Cymbellaceae	<i>Cymbella</i>
Cyanophyceae	Chroococcales	Euglenaceae	<i>Trachelomonas</i>	
Chlorophyceae	Sphaeropleales	Microcystaceae	<i>Microcystis</i>	
	Ulotrichxales	Selenastraceae	<i>Monoraphidium</i>	
		Ulotrichaceae	<i>Ulothrix</i>	
			<i>Kirchneriella</i>	
Dinophyceae	Peridinales	Peridiniaceae	<i>Peridinium</i>	
Cryptophyceae	Cryptomonadales	Cryptomonadaceae	<i>Cryptomonas</i>	
Trebouxiophyceae	Chlorellales	Oocystaceae	<i>Oocystis</i>	
Chrysophyceae	Chromulinales	Dinobryaceae	<i>Dinobryon</i>	
Zygnemophyceae	Desmidiales	Closteriaceae	<i>Closterium</i>	

The overall phytoplankton composition identified in the waters of Ranu Grati consisted of 10 classes, 14 orders, 16 families, and 18 genera, as presented in Table 1. The observations revealed that the phytoplankton community in Ranu Grati waters comprised the classes *Euglenophyceae*, *Bacillariophyceae*, *Euglenoideae*, *Cyanophyceae*, *Chlorophyceae*, *Dinophyceae*, *Cryptophyceae*, *Trebouxiophyceae*, *Chrysophyceae*, and *Zygnemophyceae*. Among these classes, *Bacillariophyceae* exhibited the highest number of genera, with six genera identified.

The dominance of *Bacillariophyceae* in freshwater phytoplankton communities is associated with its high regenerative capacity and rapid reproductive rate compared to other phytoplankton classes. Members of this class are capable of developing rapidly under conditions of low light intensity and limited nutrient availability. In addition, these phytoplankton species possess strong adaptability, enabling them to reproduce more efficiently and survive under varying environmental conditions. Nitrate availability also supports their growth and development. Consequently, *Bacillariophyceae* is considered one of the most environmentally tolerant phytoplankton groups and is highly resistant to environmental fluctuations.

Among the sampling stations, Station 3 exhibited the highest phytoplankton diversity, with a total of 15 genera identified. Meanwhile, the most dominant genus overall was *Peridinium*. The abundance of *Peridinium* recorded at each station was 85 individuals at Station 1, 41 individuals at Station 2, 53 individuals at Station 3, 15 individuals at Station 4, and 53 individuals at Station 5. Based on Table 4.2, the total abundance of *Peridinium* across all sampling stations reached 247 individuals.

Several species within the small dinoflagellate genus *Peridinium* are known to exhibit non-photosynthetic activity. *Peridinium* is regarded as a cosmopolitan genus widely distributed in freshwater and brackish water ecosystems. In tropical lakes, *Peridinium* may dominate the biomass of freshwater phytoplankton communities. This genus is considered toxic because it produces allelopathic compounds that can inhibit or eliminate other planktonic organisms. Furthermore, *Peridinium* is capable of suppressing the growth of other phytoplankton species by maintaining high biomass levels, thereby reducing competition for available nutrients. These characteristics contribute to the widespread occurrence and ecological dominance of *Peridinium* in tropical freshwater ecosystems.

Table 2. Number of Phytoplankton Individuals Identified in the Waters of Ranu Grati

Genus	Station I	Station II	Station III	Station IV	Station V	Total
<i>Monoraphidium</i>	19	38	36	39*	64*	196
<i>Synedra</i>	26	20	10	31	19	106
<i>Cryptomonas</i>	8	1	14	3	–	26
<i>Pinnularia</i>	2	6	5	–	4	17
<i>Navicula</i>	5	6	6	9	17	43
<i>Oocystis</i>	1	2	6	–	–	9
<i>Kirchneriella</i>	–	–	2	–	–	2
<i>Peridinium</i>	85*	41*	53*	15	53	247*
<i>Phacus</i>	25	22	13	4	22	86
<i>Coscinodiscus</i>	–	1	–	3	–	4
<i>Dinobryon</i>	–	–	–	–	1	1
<i>Microcystis</i>	21	24	20	20	26	111
<i>Cymbella</i>	1	3	7	3	3	17
<i>Ulothrix</i>	3	8	7	–	4	22
<i>Closterium</i>	4	–	–	–	–	4
<i>Euglena</i>	5	4	5	9	3	26
<i>Cocconeis</i>	23	36	30	29	30	148
<i>Trachelomonas</i>	18	32	45	18	45	158
Total	246	244	259	183	291*	1223

Notes:

*: highest genus abundance

I: fishing area

II: floating net cage area

III: area near the hill

IV: residential area

V: Ranau Tengah area

3.2. Diversity and Abundance of Phytoplankton in the Waters of Ranu Grati

The diversity index (H') describes the relative proportion of a species compared to the total number of individuals present within a community. Species diversity increases as the number of species and the balance of their proportions become greater. High species diversity is generally associated with good water quality, whereas low species diversity is commonly found in degraded or contaminated aquatic environments.

The results of the phytoplankton diversity index observed in the waters of Ranu Grati are presented in Table 3.

Table 3. Phytoplankton Diversity and Dominance Indices in the Waters of Ranu Grati

Variable	Station I	Station II	Station III	Station IV	Station V	Cumulative
Number of Individuals	246	244	259	183	291*	1224
Number of Genera	15	15	15	12	13	18
Shannon Index (H')	2.13 ^a	2.29 ^a	2.34 ^a	2.18 ^a	2.15 ^a	2.31
Dominance Index (D)	0.17 ^a	0.12 ^a	0.12 ^a	0.13 ^a	0.14 ^a	0.12
Evenness Index (J')	0.56	0.65	0.69	0.73*	0.66	0.56
Richness Index (Dmg)	2.54*	2.54*	2.51	2.11	2.11	2.39

Notes:

*: highest value

I: fishing area

II: floating net cage area

III: area near the hill

IV: residential area

V: Ranau Tengah area

The T-diversity test applied to phytoplankton diversity data obtained from the five sampling stations was used to assess the validity of the research findings. The results indicated that there were no statistically significant differences in phytoplankton diversity among the five sampling stations, as all p -values were greater than 0.05. This result suggests that the diversity values across all stations were relatively similar and did not differ significantly.

Based on Table 3, the highest phytoplankton diversity index in the waters of Ranu Grati was recorded at Station 3 (the area near the hill), with a value of 2.34. Station 3, which contained 15 genera, exhibited the highest diversity index due to environmental characteristics that support the growth and survival of various phytoplankton groups, particularly through sufficient nutrient availability and lower anthropogenic disturbance. Similar findings have been reported in freshwater ecosystems where phytoplankton diversity tends to increase in habitats with stable environmental conditions and adequate nutrient availability [38].

The dominance of *Bacillariophyceae* observed in Ranu Grati is consistent with studies reporting that diatoms frequently dominate freshwater phytoplankton communities because of their high adaptability and rapid reproductive capacity under varying environmental conditions. Members of this class are capable of growing under low light intensity and limited nutrient availability, allowing them to persist in fluctuating aquatic ecosystems [39].

Overall, the diversity values recorded in the waters of Ranu Grati were categorized as moderate, indicating that the aquatic ecosystem still provides relatively suitable environmental conditions for phytoplankton growth. Moderate diversity generally reflects moderate community stability and a relatively balanced distribution of genera among sampling locations. Similar ecological patterns have also been observed in mesotrophic freshwater ecosystems, where moderate phytoplankton diversity is associated with balanced environmental conditions and moderate nutrient levels [40].

The dominance index is used to determine the extent to which certain species dominate within a community. Based on Table 3, the phytoplankton dominance values among sampling stations were relatively similar; however, the highest dominance value was recorded at Station 1, with a value of 0.17. This high dominance value indicates that one genus had a substantially larger population than others. In this study, the genus *Peridinium* showed the highest abundance and dominance among all identified genera.

Several species of *Peridinium* are known to dominate tropical freshwater ecosystems because of their strong adaptability and competitive capacity. Dinoflagellates such as *Peridinium* may produce allelopathic compounds that inhibit the growth of competing phytoplankton species, thereby allowing them to maintain high biomass and dominate aquatic communities. Similar dominance patterns of dinoflagellates and cyanobacteria in eutrophic freshwater ecosystems have been widely reported [41].

The inverse relationship between diversity and dominance indices was also evident in this study. Station 1 exhibited the lowest diversity index (2.13) but the highest dominance value (0.17), indicating that the phytoplankton community was less evenly distributed due to the predominance of *Peridinium*.

The evenness index describes the distribution uniformity of individuals among species within a community. Based on Table 3, the highest evenness value was observed at Station 4, with a value of 0.73, indicating that the phytoplankton community at this station was relatively evenly distributed. High evenness values generally indicate greater ecological stability and lower competitive pressure among species.

Species richness reflects the number of different species present within a community. The highest richness values were recorded at Station 1 and Station 2, both with values of 2.54; however, these values still indicate relatively low species richness overall. Low richness may be associated with environmental pressures and nutrient imbalances that limit phytoplankton diversity. Nutrient imbalance and environmental changes are known to influence freshwater phytoplankton composition and community structure.

Phytoplankton are autotrophic organisms that function as primary producers and major oxygen contributors in aquatic ecosystems. Due to their short life cycles and rapid responses to environmental changes, phytoplankton are widely recognized as important bioindicators of water quality. Anthropogenic activities around Ranu Grati, including domestic waste disposal and floating net cage aquaculture, may contribute to water quality degradation and influence phytoplankton diversity and abundance.

Phytoplankton abundance refers to the number of phytoplankton individuals per unit volume of water. Based on Table 4, the genus *Peridinium* exhibited the highest abundance, with 247 individuals and an abundance value of 8,821 ind/L. The widespread occurrence of *Peridinium* in freshwater ecosystems is associated with its high adaptive capacity and tolerance to environmental fluctuations.

In freshwater ecosystems, excessive blooms of *Peridinium* may cause ecological disturbances because this genus can suppress the growth of other phytoplankton taxa and dominate the aquatic community structure. Similar findings regarding harmful algal dominance and bloom formation have been reported in eutrophic freshwater environments.

The highest phytoplankton abundance was recorded at Station 5 (the center of the lake), with a value of 10,393 ind/L, while the lowest abundance was found at Station 4 (the residential area), with a value of 6,536 ind/L. High abundance at Station 5 may be associated with adequate light penetration and nutrient accumulation supporting phytoplankton growth. Light intensity is recognized as a critical factor controlling phytoplankton productivity and biomass production in freshwater ecosystems [42]. In contrast, lower abundance at Station 4 may be related to anthropogenic waste inputs from nearby residential activities, which may negatively affect aquatic environmental quality.

Table 4. Phytoplankton Abundance Values in the Waters of Ranu Grati

Genus	Station I	Station II	Station III	Station IV	Station V	Total (ind/L)
<i>Monoraphidium</i>	19	38	36	39*	64*	6.928
<i>Synedra</i>	26	20	10	31	19	3.785
<i>Cryptomonas</i>	8	1	14	3	–	928
<i>Pinnularia</i>	2	6	5	–	4	607
<i>Navicula</i>	5	6	6	9	17	1.535
<i>Oocystis</i>	1	2	6	–	–	321
<i>Kirchneriella</i>	–	–	2	–	–	71
<i>Peridinium</i>	85*	41*	53*	15	53	8.821*
<i>Phacus</i>	25	22	13	4	22	3.071
<i>Coscinodiscus</i>	–	1	–	3	–	142
<i>Dinobryon</i>	–	–	–	–	1	35
<i>Microcystis</i>	21	24	20	20	26	3.964
<i>Cymbella</i>	1	3	7	3	3	607
<i>Ulothrix</i>	3	8	7	–	4	785
<i>Closterium</i>	4	–	–	–	–	142
<i>Euglena</i>	5	4	5	9	3	928
<i>Cocconeis</i>	23	36	30	29	30	5.285
<i>Trachelomonas</i>	18	32	45	18	45	5.642
Total (ind/L)	8.786	8.714	9.250	6.536	10.393*	

Notes:

*: highest abundance

I: fishing area

II: floating net cage area

III: area near the hill

IV: residential area

V: Ranau Tengah area

3.3. Analysis of Physicochemical Factors in the Waters of Ranu Grati

The biotic and abiotic factors observed in this study included phytoplankton abundance, diversity index, dominance index, temperature, water transparency, pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen, and total phosphate. The results of these parameter analyses are presented in Table 5.

Furthermore, the overall results of the physicochemical water quality analysis were compared with the lake water quality standards established under Government Regulation Number 22 of 2021 concerning environmental quality standards for aquatic ecosystems, as presented in Table 6.

Table 5. Results of Physicochemical Factor Analysis of the Waters of Ranu Grati

Parameter	Station I	Station II	Station III	Station IV	Station V
Temperature (°C)	31.7 ^a	31.8 ^a	31.7 ^a	31.7 ^a	31.8 ^a
Water Clarity (m)	0.56 ^a	0.52 ^a	0.61 ^a	0.56 ^a	0.58 ^a
pH	8.34 ^a	8.91 ^a	8.76 ^a	8.84 ^a	8.95 ^a
DO (mg/L)	4.1 ^a	4.2 ^a	4.7 ^a	4.6 ^a	4.6 ^a
BOD (mg/L)	23.7 ^a	21.4 ^a	23.2 ^a	24.0 ^a	22.6 ^a
COD (mg/L)	73 ^a	71 ^a	72.6 ^a	69.6 ^a	74 ^a
Total Nitrogen (mg/L)	0.50 ^a	0.55 ^a	0.45 ^a	0.53 ^a	0.59 ^a
Total Phosphate (mg/L)	0.373 ^a	0.269 ^a	0.333 ^a	0.202 ^a	0.306 ^a

Notes: I: residential area; II: upstream swamp area; III: area near the hill; IV: area near settlements; V: middle of the lake. Values followed by the same superscript letter within the same row indicate no significant difference based on the BNT test (α : 5%).

Table 6. Lake Water Quality Standards According to Government Regulation (PP) Number 22 of 2021

Parameter	Class 1	Class 2	Class 3	Class 4
Temperature (°C)	Dev 3	Dev 3	Dev 3	Dev 3
Water Clarity (m)	10	4	2.5	-
pH	6–9	6–9	6–9	6–9
DO (mg/L)	6	4	3	1
BOD (mg/L)	2	3	6	12
COD (mg/L)	10	25	40	80
Total Nitrogen (mg/L)	0.65	0.75	1.90	-
Total Phosphate (mg/L)	0.01	0.03	0.1	-

Based on the results of the physicochemical parameter analysis of Ranu Grati waters presented in Table 5 and their comparison with the lake water quality standards according to Government Regulation of the Republic of Indonesia Number 22 of 2021 presented in Table 6, it can be observed that the environmental condition of Ranu Grati waters is still capable of supporting phytoplankton life, although several parameters indicate signs of declining water quality. Water temperature at all sampling stations ranged from 31.7–31.8°C. These values were relatively uniform among stations and still supported phytoplankton growth, although slightly higher than the optimal temperature range for phytoplankton development, which is approximately 25–30°C. The elevated temperature was likely influenced by high solar radiation penetration at the water surface. Temperature plays an important role in regulating metabolic activity, respiration, and photosynthesis of phytoplankton. Excessively high temperatures may increase metabolic rates and oxygen demand in aquatic organisms.

Water transparency in Ranu Grati ranged from 0.52–0.61 m. These values were classified as low compared to the Class III water quality standard of 2.5 m. Low transparency indicates a high concentration of suspended particles, organic matter, and anthropogenic activities surrounding the lake, including floating net cage aquaculture, fishing activities, and domestic waste discharge. Reduced transparency can inhibit sunlight penetration into the water column, thereby limiting phytoplankton photosynthesis. Consequently, this condition may affect primary productivity and alter the distribution pattern of phytoplankton communities.

The pH values recorded at all stations ranged from 8.34–8.95 and remained within the Class III water quality standard range of 6–9. The slightly alkaline condition suggests that the waters of Ranu Grati are still suitable for the survival of aquatic organisms, including phytoplankton. The relatively stable pH values were likely influenced by phytoplankton photosynthetic activity, which utilizes dissolved carbon dioxide and subsequently reduces hydrogen ion concentration in the water. Appropriate pH conditions are essential for maintaining physiological activity and phytoplankton growth.

Dissolved oxygen (DO) concentrations ranged from 4.1–4.7 mg/L and still met the Class III water quality standard requirement of at least 3 mg/L. Adequate dissolved oxygen concentrations indicate that the waters are still capable of supplying oxygen required for aquatic organism respiration. Higher DO concentrations at several stations were presumably associated with phytoplankton photosynthetic activity and good water circulation. Dissolved oxygen is an essential parameter in determining water quality because it is directly related to the metabolic processes of aquatic organisms.

Biochemical oxygen demand (BOD) values ranged from 21.4–24 mg/L, which greatly exceeded the Class III water quality standard of 6 mg/L. Elevated BOD values indicate high concentrations of organic matter requiring substantial oxygen for microbial decomposition processes. This condition was likely caused by domestic waste input, aquaculture activities from floating net cages, residual fish feed, and tourism-related activities around the lake. High BOD levels may reduce dissolved oxygen availability, thereby negatively affecting aquatic organisms, including phytoplankton communities.

Chemical oxygen demand (COD) values at all stations ranged from 69.6–74 mg/L, exceeding the Class III water quality standard of 40 mg/L. High COD values indicate the presence of organic and inorganic substances that are difficult to decompose biologically. Increased COD concentrations are closely associated with anthropogenic pressures such as household waste, fisheries activities, and agricultural runoff surrounding the lake ecosystem. Elevated COD levels may therefore serve as an indication of ecological stress caused by pollutant accumulation in the aquatic environment.

Total nitrogen concentrations in Ranu Grati waters ranged from 0.45–0.59 mg/L and remained below the Class III water quality threshold of 1.90 mg/L. Nitrogen is an essential nutrient for phytoplankton growth because it plays a significant role in protein synthesis and photosynthetic processes. Nitrogen concentrations within the acceptable range indicate that nutrient availability is still sufficient to support phytoplankton productivity without causing excessive eutrophication.

In contrast, total phosphate concentrations ranged from 0.202–0.373 mg/L and exceeded the Class III water quality standard of 0.1 mg/L. Elevated phosphate concentrations suggest significant nutrient input into the lake ecosystem, primarily originating from domestic waste, detergents, agricultural activities, and residual feed from aquaculture practices. Phosphate is recognized as one of the primary limiting nutrients in aquatic productivity; therefore, increased phosphate concentrations may trigger eutrophication and phytoplankton blooms. If such conditions persist continuously, they may lead to ecological imbalance within the aquatic ecosystem.

Overall, the physicochemical parameter analysis indicates that the water quality of Ranu Grati can be categorized as moderately polluted and classified within the Class III water quality category. Although the environmental condition still supports phytoplankton survival, the elevated BOD, COD, and total phosphate concentrations demonstrate that anthropogenic activities surrounding the lake have exerted considerable pressure on water quality. Therefore, sustainable environmental management and continuous monitoring are necessary to maintain the ecological balance and preserve the water quality of Ranu Grati Lake.

3.4. Correlation Between Phytoplankton Diversity and the Physicochemical Parameters of Ranu Grati Waters

Correlation analysis between the physicochemical factors of aquatic environments and the abundance of phytoplankton genera is important for understanding how environmental conditions influence the presence and distribution of specific phytoplankton genera within the ecosystem. In this study, the physicochemical parameters analyzed included temperature, water transparency, pH, dissolved oxygen (DO), biological oxygen demand (BOD), chemical oxygen demand (COD), total nitrogen, and total phosphate.

The results of the correlation analysis indicate either positive or negative relationships between phytoplankton abundance and the measured physicochemical parameters, as presented in Table 7.

Table 7. Correlation Values Between Phytoplankton Abundance and Physicochemical Parameters of Ranu Grati Waters

Genus	Temperature (T)	Transparency (K)	pH	DO	BOD	COD	Total Nitrogen (N)	Total Phosphate (F)
X1 (Euglena)	0.327	0.821	-	-	-	-	0.770	-0.966
X2 (Cocconeis)	-0.429	0.985	0.531	0.944	0.760	0.906	0.102	-0.869
X3 (Trachelomonas)	0.293	-0.999	0.215	0.902	0.997	0.942	-0.246	0.932
X4 (Microcystis)	-0.240	0.999	-	0.955	0.917	0.981	0.299	-0.950
X5 (Monoraphidium)	-0.992	0.147	0.071	0.970	0.991	0.990	-0.912	0.196
X6 (Peridinium)	0.633	0.574	0.015	-	-	-	0.245	-0.817
X7 (Phacus)	0.591	-0.936	0.791	0.773	0.489	0.704	0.943	0.761
X8 (Navicula)	-0.866	-0.247	-	0.806	0.966	0.863	0.085	0.561
X9 (Synedra)	0.866	0.205	0.395	0.954	0.500	0.149	0.407	-0.999
X10 (Cryptomonas)	0.327	-0.998	0.961	-	-	-	0.997	-0.524
X11 (Pinnularia)	-0.427	0.985	0.104	0.462	0.106	0.367	-0.211	0.918
			0.216	-	-	-	0.105	-0.869

				0.904	0.997	0.943		
X12 (<i>Oocystis</i>)	-1.000	0.093	0.994	0.520	0.997	0.994	-0.520	0.997
X13 (<i>Kirchneriella</i>)	0.866	-0.715	-	0.500	0.781	0.586	0.479	0.436
X14	0.327	-0.998	-	0.944	0.979	0.973	-0.211	0.918
(<i>Coscinodiscus</i>)			0.106					
X15 (<i>Dinobryon</i>)	0.866	0.247	-	-	-	-	0.999	-0.561
X16 (<i>Cymbella</i>)	-0.720	0.862	0.956	0.500	0.149	0.407		
X17 (<i>Ulothrix</i>)	-0.817	0.775	0.546	-	-	-	-0.254	-0.639
X18 (<i>Closterium</i>)	0.866	0.247	0.666	-	-	-	-0.398	-0.516
			0.576	0.835	0.657			
			-	-	-		0.999	-0.561
			0.956	0.500	0.149	0.407		

Notes: Bold values indicate the highest correlation coefficients. X1 = *Euglena*, X2 = *Cocconeis*, X3 = *Trachelomonas*, X4 = *Microcystis*, X5 = *Monoraphidium*, X6 = *Peridinium*, X7 = *Phacus*, X8 = *Navicula*, X9 = *Synedra*, X10 = *Cryptomonas*, X11 = *Pinnularia*, X12 = *Oocystis*, X13 = *Kirchneriella*, X14 = *Coscinodiscus*, X15 = *Dinobryon*, X16 = *Cymbella*, X17 = *Ulothrix*, X18 = *Closterium*; T = Temperature, K = Transparency, DO = Dissolved Oxygen, BOD = Biological Oxygen Demand, COD = Chemical Oxygen Demand, N = Total Nitrogen, and F = Total Phosphate.

The correlation analysis conducted using PAST 4.03 software revealed that water temperature had a strong negative correlation with the genus *Oocystis* ($r = -1$). This result indicates that phytoplankton diversity decreased as water temperature increased. The correlation strength between temperature and phytoplankton diversity was categorized as very strong. Elevated temperatures may increase the metabolic and respiratory activities of aquatic organisms, which can ultimately reduce phytoplankton diversity and disrupt plankton survival. This finding is consistent with previous studies reporting that temperature significantly affects phytoplankton metabolism, growth, and community composition in freshwater ecosystems [43].

The Pearson correlation analysis between water transparency and phytoplankton diversity showed two genera with very strong relationships, namely *Trachelomonas* ($r = -0.99$) and *Microcystis* ($r = 0.99$). The negative correlation observed in *Trachelomonas* indicates that increasing water transparency was associated with lower diversity of this genus. In contrast, *Microcystis* exhibited a strong positive correlation with transparency, indicating that increased transparency was followed by increased diversity of *Microcystis*. This finding suggests that light penetration plays an essential role in supporting phytoplankton growth and photosynthetic activity. Suspended solids originating from organic and inorganic waste may reduce water transparency and limit sunlight penetration, thereby affecting photosynthetic organisms such as phytoplankton. Similar observations have been reported in studies discussing the relationship between turbidity, light availability, and phytoplankton productivity.

The Pearson correlation analysis further demonstrated that pH had a strong positive correlation with the genus *Monoraphidium* ($r = 0.99$), indicating a very close relationship between pH and the abundance of this genus. The positive correlation suggests that higher pH values were associated with higher abundance of *Monoraphidium*, whereas lower pH values corresponded to lower abundance. Thus, the presence of *Monoraphidium* was directly proportional to pH conditions in the aquatic environment. Water pH reflects hydrogen ion activity and serves as an important indicator of aquatic environmental quality. Increased phytoplankton activity may elevate pH through the absorption of bicarbonate and dissolved carbon dioxide during photosynthesis. Most aquatic organisms generally thrive in waters with pH values ranging from 7 to 8.5. Similar findings regarding the influence of pH on freshwater phytoplankton communities have been widely reported.

The Pearson correlation analysis between dissolved oxygen (DO) and phytoplankton diversity showed that the genus *Oocystis* had a very strong positive correlation with DO ($r = 1$). This result indicates that increases in dissolved oxygen were accompanied by increases in *Oocystis* diversity. Dissolved oxygen is essential for respiration, metabolism, and energy production in aquatic organisms, including phytoplankton. Adequate oxygen availability therefore supports phytoplankton growth and reproduction. Similar relationships between dissolved oxygen and phytoplankton abundance have been documented in freshwater ecological studies [44].

The Pearson correlation analysis also showed that biological oxygen demand (BOD) had a strong positive correlation with the genus *Cryptomonas* ($r = 0.99$). This indicates that higher BOD values were associated with greater abundance of *Cryptomonas*. BOD is commonly used as an indicator of organic pollution in aquatic ecosystems because it reflects the amount of oxygen required by microorganisms to decompose organic matter. Waters with higher BOD values generally contain higher concentrations of organic materials. Variations in BOD levels are closely related to bacterial activity involved in the decomposition and oxidation of organic waste materials. Similar findings regarding BOD as an indicator of organic pollution have been discussed in aquatic environmental studies.

Similarly, the Pearson correlation analysis between chemical oxygen demand (COD) and phytoplankton diversity showed that *Oocystis* had a very strong positive correlation with COD ($r = 0.99$). This positive relationship indicates that increasing COD values were associated with higher diversity of *Oocystis*. Both BOD and COD indirectly represent the concentration of organic matter in aquatic environments, reflecting the amount of oxygen required for the oxidation and decomposition of organic substances. The decomposition process produces inorganic nutrients that can subsequently be utilized by phytoplankton and periphyton for growth and development. Comparable results have been reported regarding the ecological significance of COD in freshwater ecosystems [45].

The Pearson correlation analysis between total nitrogen and phytoplankton diversity demonstrated very strong positive correlations for the genera *Dinobryon* and *Closterium* ($r = 0.99$). This result indicates that increased total nitrogen concentrations were associated with increased diversity of both genera. Nitrogen is an essential nutrient for phytoplankton because it forms a major component of cellular protoplasm and is required for protein synthesis and other metabolic processes. Therefore, nitrogen availability strongly influences phytoplankton productivity and community composition. Similar conclusions have been reported in studies examining nutrient limitation and phytoplankton dynamics in freshwater environments.

Furthermore, the Pearson correlation analysis between total phosphate and phytoplankton diversity showed that *Oocystis* exhibited a very strong positive correlation with total phosphate ($r = 0.99$). This positive relationship indicates that increasing phosphate concentrations were followed by increases in *Oocystis* diversity. Dissolved phosphate is readily absorbed by phytoplankton and often functions as a limiting nutrient in aquatic ecosystems. Consequently, phosphate availability plays a crucial role in regulating phytoplankton growth, productivity, and community dynamics. Similar findings regarding phosphate as a limiting factor for phytoplankton growth have been widely discussed in limnological studies. \

The novelty of this study lies in its integrated analytical approach combining phytoplankton community structure with physicochemical water parameters through comprehensive correlation analysis in the Ranu Grati Lake ecosystem. Unlike previous studies that mainly focused on specific nutrient relationships or partial phytoplankton identification, this research simultaneously analyzed diversity, dominance, abundance, and ecological relationships between phytoplankton communities and water quality parameters based on the national water quality standards of Government Regulation of the Republic of Indonesia Number 22 of 2021. This approach provides a more comprehensive ecological overview of water conditions and phytoplankton community dynamics in tropical lake ecosystems.

The implications of this study indicate that phytoplankton can serve as effective bioindicators for sustainable water quality monitoring, particularly in lake ecosystems experiencing anthropogenic pressures from domestic activities, fisheries, tourism, and floating net cage aquaculture. The findings of this study may also provide a scientific basis for environmental management and the development of lake conservation strategies oriented toward pollution control, nutrient management, and the preservation of aquatic ecosystem balance. However, this study still has several limitations, including the relatively short sampling period, which may not fully represent the seasonal dynamics of Ranu Grati waters. In addition, phytoplankton identification was limited to the genus level and did not include molecular analysis or other biological parameters such as chlorophyll-*a* concentration and phytoplankton biomass. Therefore, future studies are recommended to conduct long-term monitoring with broader ecological parameters in order to obtain a deeper understanding of water quality dynamics and phytoplankton community structure in the waters of Ranu Grati.

4. CONCLUSION

Based on the analysis of phytoplankton abundance and physicochemical parameters in the waters of Ranu Grati, it can be concluded that the water quality condition is still capable of supporting phytoplankton life, although several parameters indicate moderate ecological pressure caused by anthropogenic activities. A total of 18 phytoplankton genera were identified, consisting of members from the divisions Chlorophyta, Bacillariophyta, Euglenophyta, Cyanophyta, Chrysophyta, and Dinophyta. The presence of diverse phytoplankton genera reflects the ecological dynamics and nutrient availability within the aquatic ecosystem. The physicochemical characteristics of the waters showed that temperature, pH, dissolved oxygen (DO), and total nitrogen concentrations were still within the permissible limits of the Class III water quality standard according to Government Regulation of the Republic of Indonesia Number 22 of 2021. However, water transparency, biochemical oxygen demand (BOD), chemical oxygen demand (COD), and total phosphate concentrations exceeded the established quality standards, indicating the influence of organic pollution and nutrient enrichment originating from domestic activities, aquaculture practices, fisheries, and tourism around the lake area. Correlation analysis demonstrated that phytoplankton abundance was strongly influenced by several physicochemical parameters, particularly transparency, dissolved oxygen, BOD, COD, total nitrogen, and total phosphate. Elevated nutrient concentrations, especially phosphate, contributed significantly to phytoplankton distribution and abundance patterns in the waters of Ranu Grati. Overall, the findings indicate that the aquatic

ecosystem of Ranu Grati is experiencing moderate pollution pressure, although it still maintains ecological conditions suitable for phytoplankton growth and survival. Further interdisciplinary studies focusing on sustainable lake management strategies, pollution mitigation, and community-based environmental conservation are necessary to support the long-term preservation of the ecological balance and water quality of Ranu Grati.

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AUTHOR CONTRIBUTIONS

Conceptualization, N.B.J. and P.M.; Methodology, N.B.J.; Software, N.B.J.; Validation, N.B.J. and P.M.; Formal Analysis, N.B.J.; Investigation, N.B.J.; Resources, P.M.; Data Curation, N.B.J.; Writing – Original Draft Preparation, N.B.J.; Writing – Review & Editing, N.B.J. and P.M.; Visualization, N.B.J.; Supervision, P.M.; Project Administration, N.B.J.; Funding Acquisition, P.M.

CONFLICTS OF INTEREST

The authors declare no conflict of interest.

USE OF ARTIFICIAL INTELLIGENCE (AI)-ASSISTED TECHNOLOGY

Not applicable.

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