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ARTICLE

PRELIMINARY STUDY OF INDIGENOUS MICROALGAE FROM URBAN AND PEATLAND WATERS IN PEKANBARU UNDER NUTRIENT-LIMITED MEDIA

[*Studi Pendahuluan Mikroalga Indigenous dari Perairan Perkotaan dan Gambut di Pekanbaru pada Media Terbatas Nutrien*]

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ABSRACT

Microalgae inhabiting urban waters and peat-influenced aquatic systems experience variable environmental pressures, potentially leading to adaptive responses to conditions with fluctuating nutrient availability. This study aimed to identify microalgae cultured from several urban water bodies and peat waters in Pekanbaru and to evaluate their growth responses in culture media with different nutrient compositions using an image-based approach. Water samples were collected from multiple locations and cultured in modified BG-11 and BBM media. The growing microalgae were identified based on their morphological characteristics, while culture growth was qualitatively assessed using the mean pixel intensity (MPI) values of digital images. The study recorded 16 species from 10 microalgal genera belonging to the classes Cyanophyceae, Chlorophyceae, and Zygnematophyceae, exhibiting unicellular, colonial, and filamentous morphologies. Culture observations revealed changes in MPI values over the observation intervals, indicating increased microalgal growth rates in the growth media. These findings suggest that local microalgae from urban and peat waters possess a high tolerance to limited nutrient conditions and provide baseline information on the diversity and growth responses of indigenous microalgae in tropical urban and peat aquatic systems.

Keywords: Adaptation, limited nutrients, microalgae, peat, Pekanbaru

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ABSTRAK

Mikroalga yang hidup pada perairan urban dan perairan yang dipengaruhi oleh gambut mendapat tekanan lingkungan yang variatif sehingga berpotensi menunjukkan respons adaptif terhadap kondisi lingkungan dengan ketersediaan hara yang bervariasi. Penelitian ini bertujuan untuk mengidentifikasi mikroalga yang dikultivasi dari beberapa badan air urban dan perairan gambut di Pekanbaru serta mengevaluasi respons pertumbuhannya pada media kultur dengan komposisi nutrien yang berbeda menggunakan pendekatan gambar. Sampel air dikumpulkan dari beberapa lokasi dan dikultur pada media modifikasi BG-11 dan BBM. Mikroalga yang tumbuh diidentifikasi berdasarkan karakteristik morfologi, sedangkan pertumbuhan kultur diamati secara kualitatif menggunakan nilai mean pixel intensity (MPI) gambar. Hasil penelitian mengamati 16 spesies dari 10 genus mikroalga mencakup kelas cyanophyceae, chlorophyceae, dan zygnematophyceae yang memiliki morfologi uniseluler, koloni, dan filamen. Pengamatan kultur menunjukkan perubahan nilai MPI selama interval pengamatan yang mengindikasi peningkatan laju pertumbuhan mikroalga pada medium pertumbuhan. Temuan ini menunjukkan bahwa mikroalga lokal dari perairan urban dan gambut memiliki tingkat toleransi yang tinggi terhadap nutrien yang terbatas serta menyediakan informasi dasar mengenai keanekaragaman dan respons pertumbuhan mikroalga indigenus pada sistem perairan urban dan gambut tropis.

***Kata kunci**: Adaptasi, mikroalga, gambut, nutrient, Pekanbaru*

INTRODUCTION

Pekanbaru City, Riau Province, Indonesia, is characterized by wetland ecology influenced by peatland ecosystems as well as the presence of palm oil and petroleum industries. Data from Statistics Indonesia (Badan Pusat Statistik, BPS) indicate that Pekanbaru had 7,817 small-scale industries in 2024, while medium and large industries totaled 47 units in 2022 (Badan Pusat Statistik, 2025). Meanwhile, the Riau Provincial Plantation Agency reported a 3.6% increase in oil palm plantation area in Pekanbaru, reaching 18,438 hectares in 2024 compared to the previous year (Dinas Perkebunan Provinsi Riau, 2025). These varying environmental conditions create unique habitats for indigenous microalgae, making the region strategically important for exploring local microalgae that are adaptive to nutrient limitations and extreme environmental conditions.

Microalgae are photosynthetic organisms that play essential roles in ecosystems (Sahoo & Baweeja, 2015). They hold strong potential for applications in bioremediation (Danouche *et al*., 2021; Andriani *et al*., 2025), biomass production, and biorefinery development such as biofuels due to their diverse metabolites, including polysaccharides, lipids, amino acids, and pigments (Rico *et al*., 2017; Sathasivam *et al*., 2019; Babu *et al*., 2022). In addition to their valuable metabolites, microalgae exhibit remarkable adaptability to extreme ecosystems such as peat waters and wastewater environments (Gomes *et al*., 2021).

Peat waters possess distinctive environmental characteristics, including high concentrations of dissolved organic matter and the availability of inorganic nutrients such as silica (Si), iron (Fe), and manganese (Mn) (Bendell-Young, 2003; Qadafi *et al*., 2023). High levels of organic compounds, such as humic and fulvic acids, result in brown-colored water and low pH conditions (Notodarmojo *et al*., 2017). The acidity (pH) of the Siak River, influenced by peat drainage in the Pekanbaru region, ranges from 3 to 4 (Qadafi *et al*., 2023).

In contrast, urban water bodies in Pekanbaru are influenced by anthropogenic activities such as domestic and industrial wastewater, which introduce elevated concentrations of nitrogen and phosphate into aquatic systems. Studies conducted in several rivers in Pekanbaru, including the Air Hitam River, Umban River, and Sibam River (a tributary of the Siak River), reported pollutant loads ranging from 18,163.2–105,235 kg/day (TSS), 3.84–10,982.4 kg/day (BOD), 15.415–20.26 kg/day (COD), 249.22 kg/day (nitrate), and approximately 234–241 kg/day (total phosphate) (Yuliati *et al*., 2022; Saputra *et al*., 2023; Putri *et al*., 2025).

Differences in physicochemical water conditions may act as selective pressures, prompting microalgae to develop adaptive mechanisms. Adaptation to environmental conditions can influence growth patterns, nutrient-use efficiency, and resilience to environmental stress (Abdelfattah *et al*., 2023). *Chlorella sorokiniana* maintained growth and exhibited increased lipid accumulation when cultured under limited nitrogen (0.42–1.53 mg/L) and phosphorus (0.37 mg/L) conditions

(Shriwastav *et al*., 2014). Similarly, *Chlamydomonas* showed increased expression of proteins involved in nitrogen transport and nitrogen assimilation enzymes, including nitrate reductase, nitrite reductase, and glutamine synthetase, as an adaptive response to nitrogen limitation (Saroussi *et al*., 2017).

The use of nutrient-limited media in microalgal culture studies represents an important approach to simulate the natural conditions of peat and urban waters which have limited nutrients. Peatland aquatic ecosystems, including peat swamps, are generally characterized by limited availability of the macronutrients phosphorus (P) and nitrogen (N) (Verhoeven, 1986; Salmon *et al*., 2021). Furthermore, low concentrations of the micronutrient molybdenum (Mo) have also been reported in peatland environments (Warren *et al*., 2017). Low-nutrient media allows the evaluation of microalgal adaptive capacity under nutrient-restricted conditions that more closely resemble their native habitats, while also being relevant for the development of more efficient and sustainable microalgal cultivation systems, particularly in wastewater management.

Although previous studies have investigated the growth performance of microalgae in tropical peat waters from Rimbo Panjang, Pekanbaru, Riau (Padil *et al*., 2022), knowledge regarding their adaptive capacity under extreme environmental conditions, particularly nutrient limitation, remains limited. The lack of studies integrating peat water characteristics with adaptive microalgal responses under nutrient-limited media highlights the urgency of further research to enhance understanding of microalgal ecophysiology.

Based on this background, this study aims to explore indigenous microalgae from urban and peat waters in Pekanbaru and to assess their adaptive capacity under nutrient-limited culture conditions. The findings are expected to provide baseline information on the adaptive potential of local microalgae and to support the sustainable development of microalgal applications in environmental and biotechnological fields.

MATERIALS AND METHODS

Sample Collection

A total of 11 freshwater sampling stations were selected, including three artificial lakes (L1–L3) within Universitas Riau, two ponds (L4 and L7), four drainage channels and ditches (L5, L6, L8, L9, and L11), and one river site (L10). The stations were distributed across Pekanbaru City and Kampar Regency. Several stations located in Kubang Raya and Rimbo Panjang were situated within areas associated with peatland ecosystems of the Kampar watershed, whereas the remaining stations represented urban freshwater habitats (Figure 2.1). Approximately 100 mLof water was collected and stored in polyethylene terephthalate (PET) bottles. The samples were subsequently observed and cultured by the Microbiology Laboratory, Faculty of Mathematics and Natural Sciences, Universitas Riau (UNRI).

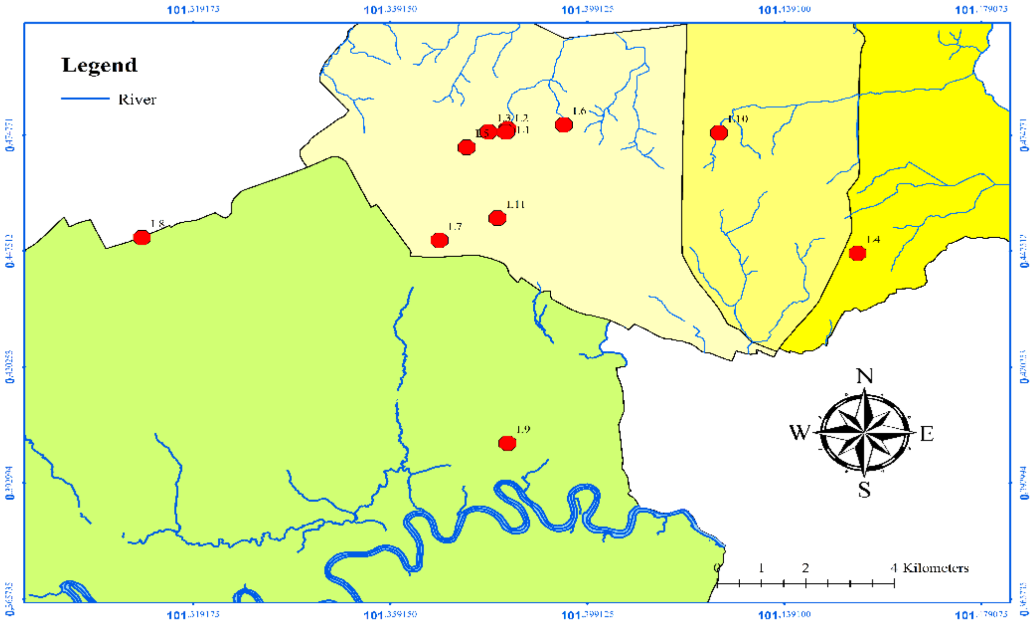

Figure 1. Sampling locations (*Lokasi Sampling*).

Culture Preparation

Water samples were cultured in modified Bold's Basal Medium (BBM) and Blue-Green Medium No. 11 (BG-11) based on the formulations of Bischoff and Bold (1963) and Stanier *et al*. (1971), respectively. The modified media consisted of selected macro- and micronutrients, including phosphate, calcium, magnesium, and molybdenum, while several components present in the original formulations were omitted to establish nutrient-limited culture conditions (Table 2.1). These modifications were intended to evaluate the adaptive responses of microalgae under reduced nutrient availability. Microalgal isolates obtained from Universitas Riau were selected for further culture experiments, considering laboratory constraints and culture feasibility.

Stock solutions were prepared in 100 mL and separately combined for each medium to obtain 1 L of final culture medium. Each medium was subsequently sterilized by autoclaving before inoculation. Six sterile 100 mL Erlenmeyer flasks were prepared under aseptic conditions for microalgal cultivation. Cultures were incubated at room temperature (26–30°C) under a 16:8 h light–dark photoperiod.

Table 1. Composition of BBM and BG-11 media (*Komposisi media BBM dan BG-11*).

Components (*Komponen*)	**Stock solution** (*Larutan Stok*) **(g/100 mL)**		**Quantity used** (*Jumlah yang digunakan*) **(mL/L)**	
	BBM	**BG-11**	**BBM**	**BG-11**
KH_2PO_4	1.75	-	10	-
K_2HOP_4	0.75	0.4	10	10
$CaCl_2.2H_2O$	0.25	0.36	10	10
$MgSO_4.7H_2O$	0.75	0.75	10	10
NaCl	0.25	-	10	-
Ferric amonium citrate	-	0.06	-	10
Na_2CO_3	-	0.2	-	10
MoO_3	0.071	0.039	1	1

Morphological Observation

Microalgae were observed directly from water samples and culture results. Observations were conducted using a light microscope (Olympus CX23) at magnifications of 4–100×. Morphological characteristics such as cell shape, color, presence of flagella, and chloroplast morphology were recorded and compared with taxonomic references, including Freshwater Algae of North America by Wehr, Sheath, and Kociolek (2015), as well as relevant scientific literature.

Growth Observation

Growth observation was conducted following Sunoj *et al*. (2021) using an image-based approach to monitor microalgal growth dynamics. Cultures were incubated for three weeks and observations were conducted on day 0 (T1), day 7 (T2), day 14 (T3), and day 21 (T4). At each observation point, photographs were taken inside a custom-built imaging box lined with black fabric to minimize external light interference and ensure consistent illumination conditions. Images were standardized by defining a Region of Interest (ROI) of 200 × 180 pixels to ensure comparability among samples. The images were processed using ImageJ version 1.54 (NIH, USA). Prior to analysis, images were converted to 8-bit format, and Mean Pixel Intensity (MPI) was quantified using the Analyze and Measure function.

The MPI values were used as a proxy for relative biomass accumulation and growth performance. Higher MPI values indicated increased cell density and pigmentation intensity, while lower values reflected reduced growth or delayed adaptation. The temporal changes in MPI over the three-week period were plotted using Microsoft Office Excel 2021 to generate growth curves, allowing comparison of growth performance among treatments.

Data Analysis

Microalgal growth data and their relationships with ecological conditions were analyzed and visualized using Microsoft Excel 2021 to evaluate growth performance under nutrient-limited conditions and its association with environmental factors.

RESULTS

Diversity and Distribution of Microalgae from Various Water Body

A total of ten microalgal genera belonging to three classes, namely Cyanophyceae, Chlorophyceae, and Zygnematophyceae, were identified across all sampling sites. The observed taxa exhibited diverse morphological forms, including unicellular, colonial, and filamentous microalgae (Figure 2). The class Cyanophyceae was represented by *Microcystis* sp. (Figure 2A) and *Oscillatoria* sp. (Figure 2J). *Microcystis* sp. formed non-filamentous colonies of spherical cells embedded in mucilage, whereas *Oscillatoria* sp. exhibited unbranched filamentous morphology with gliding motility and lacked heterocysts (Whitton & Potts, 2012).

The class Chlorophyceae showed the highest genus richness in this study and was represented by *Chlorella* sp. (Figure 2 E, M, P), *Chlamydomonas* (Figure 2H)., *Scenedesmus* sp. (Figure 2B–D), *Staurodesmus* sp. (Figure 2F), *Pediastrum* sp. (Figure 2G), and *Kirchneriella* sp. (Figure 2O). This class displayed considerable morphological diversity ranging from unicellular coccoid forms to colonial and coenobial structures. *Chlorella* sp. was the most frequently observed genus and consisted of small spherical non-motile cells with a single chloroplast, whereas *Chlamydomonas* sp. was characterized by flagellated motile cells (Bellinger & Sigee, 2010; Richmond, 2004). Colonial chlorophytes such as *Scenedesmus* sp. formed coenobia of 4–8 cells with elongated morphology and thickened cell walls (Wehr *et al*., 2015), while *Staurodesmus* sp. was characterized by a median constriction and spiny semicells.

The class Zygnematophyceae was represented by the filamentous genera *Spirogyra* (Figure 2K–L) and *Zygnema* (Figure 2I). Members of Zygnematophyceae, commonly referred to as conjugating green algae, are regarded as the closest extant algal relatives of terrestrial plants (Pichrtová *et al*., 2018). They are recognized as ecologically dominant taxa in specific habitats, including peatland ecosystems (Coesel & Meesters, 2014) and freshwater pools (Šťastný, 2008).

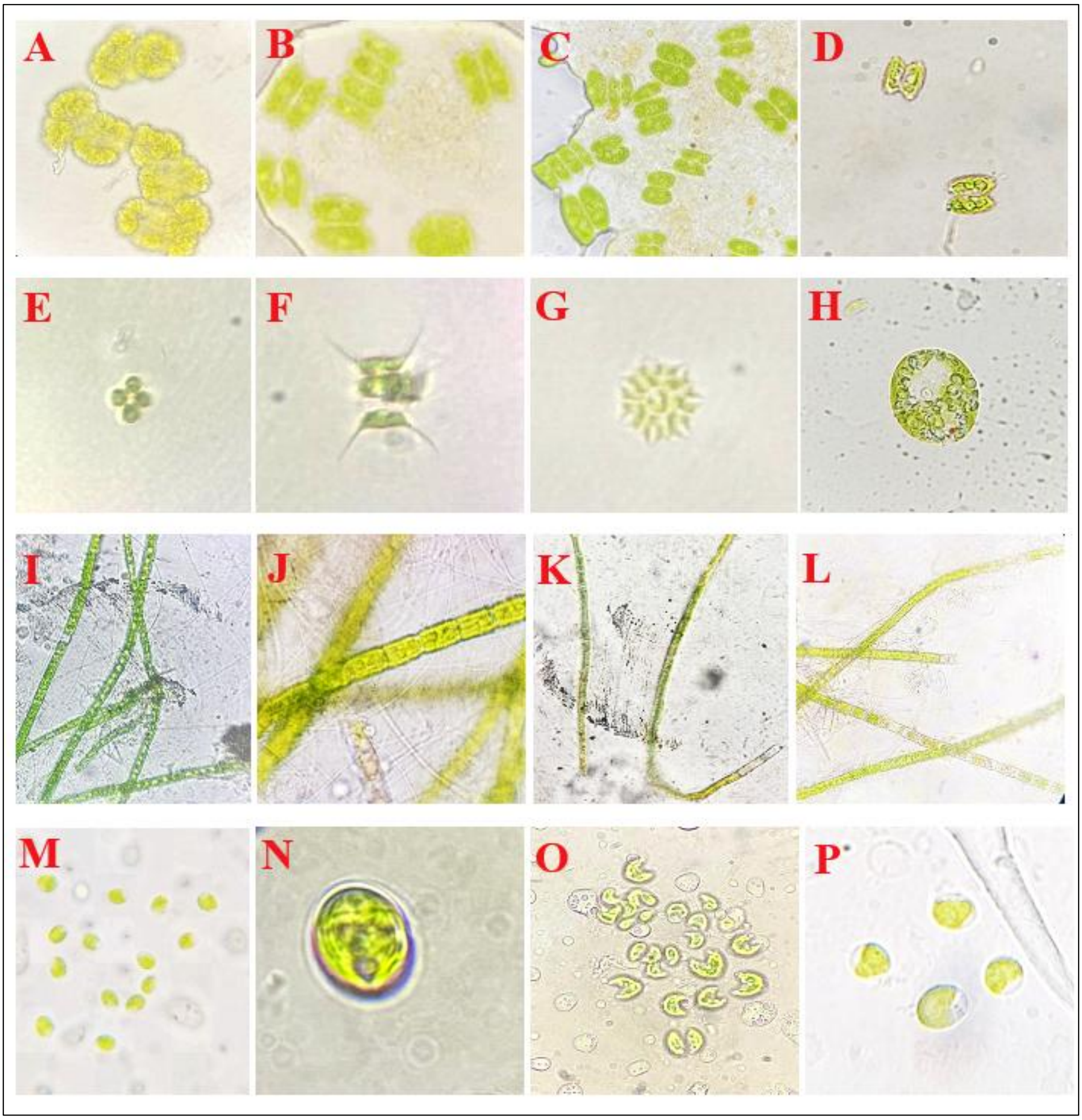

Figure 2. Morphological diversity of microalgae from urban waters and peatland-influenced sites in Pekanbaru (*Keanekaragaman morfologi mikroalga dari perairan perkotaan dan situs yang dipengaruhi lahan gambut di Pekanbaru*). Ket. *(Remark*): Observations were conducted at 4–100× magnification (*Pengamatan dilakukan pada pembesaran 4–100×*). Representative microalgal taxa include (*Taksa mikroalga representatif meliputi*): *Microcystis* sp. [A]; *Scenedesmu*s sp. [B–D]; *Chlorella* sp. [E, H, M, P]; *Staurodesmus* sp. [F]; *Pediastrum* sp. [G]; *Zygnem*a sp. [I]; *Kirchneriella* sp. [O]; *Spirogyra* sp. [K–L]; *Oscillatoria* sp. [J]; and *Chlamydomona*s sp. [N].

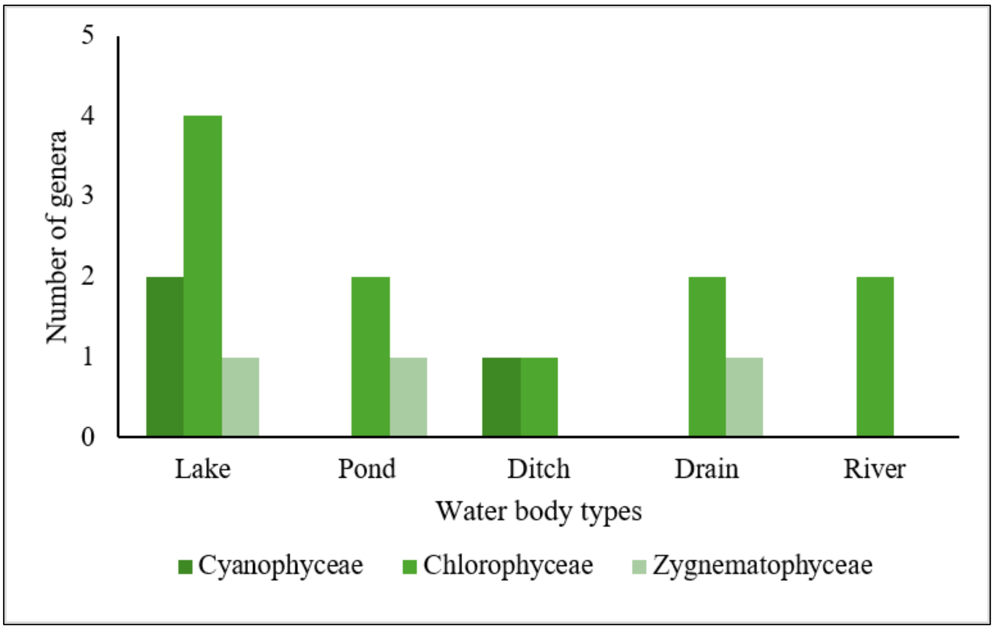

Figure 3. Distribution of microalgal classes across different water body types (*Distribusi kelas mikroalga di berbagai tipe badan air*).

The distribution of microalgal classes varied among different water body types (Figure 3). Chlorophyceae were found in all water types, including lakes, rivers, ditches, drains, and ponds, and exhibited the highest number of genera compared to Cyanophyceae and Zygnematophyceae. Cyanophyta were detected in lakes, rivers, and ditch channels, while Zygnematophyceae were present in lakes, drains, rivers, and ponds. Lakes showed the highest overall diversity among all water bodies. The identified microalgae and their sampling locations are presented in Table 2.

Lake habitats exhibited the highest genus richness, with seven genera identified, including four Chlorophyceae, two Cyanophyceae, and one Zygnematophyceae. Ponds and drainage channels each contained three genera, dominated by Chlorophyceae (two genera) and Zygnematophyceae (one genus). Ditches contained two genera, represented by Chlorophyceae and Cyanophyceae, while river habitats contained two genera, both belonging to Chlorophyceae.

Table 2. Identification of Microalgae and Sampling Locations (*Identifikasi Mikroalga dan Lokasi Pengambilan Sampel*).

Genus Name (*Nama Genus*)	**Source Location** (*Lokasi Sumber*)	**Main Characteristics** (*Karakter Utama*)	**Reference** (*Referensi*)
Microcystis sp. [A]	L1	Cyanobacteria colony, small spherical cells embedded in mucilage; non-filamentous (Koloni *Cyanobacteria, sel kecil berbentuk bola yang tertanam di lendir; tidak berfilamen)*	Whitton & Potts, (2012)
Scenedesmus sp. [B–D]	L1, L2, L3, L4, L10	Green algae colony (4–8 cells); elongated elliptical cells arranged in parallel; sometimes spiny; thick cell wall (*Koloni alga hijau (4–8 sel); sel elips memanjang yang tersusun paralel; kadang-kadang berduri; dinding sel tebal*)	Bellinger & Sigee, (2010)
Chlorella sp. [E, M, P]	L1, L2, L3, L5, L6, L8, L10	Unicellular green algae; small spherical cells; single chloroplast; non-flagellated (*Alga hijau uniseluler; sel bola kecil; kloroplas tunggal; tidak ada flagel*)	Wehr *et al*., (2015); Shubert & Gartner, (2015)

Genus Name (*Nama Genus*)	**Source Location** (*Lokasi Sumber*)	**Main Characteristics** (*Karakter Utama*)	**Reference** (*Referensi*)
Staurodesmus sp. [F]	L3	Bilaterally symmetrical desmid; constricted cells with arms/spines; indicator of acidic and oligotrophic waters (*Desmid simetris bilateral; sel yang menyempit dengan lengan/duri; indikator air asam dan oligotrofik*)	Brook, (1981)
Pediastrum sp. [G]	L3	Flat, disc-shaped green algal colony; radially arranged cells; colony margins lobed or serrated (*Koloni alga hijau berbentuk cakram datar; sel-sel yang tersusun secara radial; Tepi koloni berlobus atau bergerigi*)	John *et al*., (2011)
Zygnema sp. [I]	L7	Unbranched filamentous green algae; cylindrical cells with distinct septa; two ribbon-shaped chloroplasts; bright green color (*Alga hijau filamen tanpa cabang; sel silinder dengan septa yang berbeda; dua kloroplas berbentuk pita; warna hijau cerah*)	Komárek & Anagnostidis, (2005)
Kirchneriella sp. [O]	L7, L9	Crescent-shaped unicellular green algae; bright green chloroplast; non-flagellated (*Alga hijau berbentuk bulan sabit satu seluler; kloroplas hijau cerah; tidak ada flagel)*	Lee, (2008)
Spirogyra sp. [K–L]	L5	Unbranched filamentous green algae; large cylindrical cells; spiral-shaped chloroplast (*Alga hijau filamen tanpa cabang; sel silinder besar; kloroplas berbentuk spiral*)	Graham *et al*., (2009)
Oscillatoria sp. [J]	L1, L11	Filamentous cyanobacteria; unbranched; without heterocysts; gliding (oscillatory) movement (*Sianobakteri filamen; tidak bercabang; tanpa heterocyst; gerakan meluncur (osilasi))*	Whitton & Potts, (2012)
Chlamydomonas sp. [N]	L2	Unicellular green algae; two flagella; cup-shaped chloroplast; eyespot present; motile (*Alga hijau uniseluler; dua flagela; kloroplas berbentuk cangkir; Ada bintik mata; bergerak*)	Harris, (2009)

Effect of Limited Culture Media on Microalgal Growth

The mean pixel intensity (MPI) values of microalgae showed variation across culture media, sampling locations, and observation times. In BBM medium, all samples (L1, L2, and L3) exhibited an increase in MPI values increased from T1 (day 0) to T2 (day 7) (Figure 4). Sample L1 exhibited the highest MPI value at T1 (day 7), reaching 163.172. At T2 (day 14), the highest MPI values were recorded in samples L2 (157.882) and L3 (149.892). However, a decline in MPI values was observed in all samples on T3 (day 21), indicating a possible decline in phase or adaptation stage after reaching peak growth.

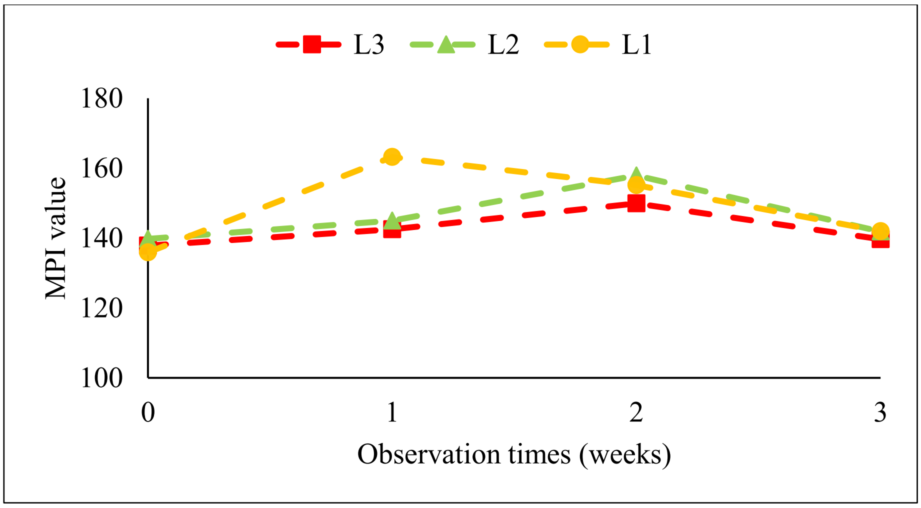

Figure 4. Growth rate of microalgal cultures in BBM medium (*Laju pertumbuhan kultur mikroalga dalam media BBM*).

In BG-11 medium, the growth pattern from all cultures showed an increase from observation T0 to T2. The highest MPI value observed in sample L3 (154.448) in T2 (Figure 5). Samples L1 and L2 exhibited fluctuating patterns, with an increase on T1 followed by a decline on T2. During the third observation period (T3), MPI values differed among the three samples, with the highest value recorded in L1 (140.138) and the lowest in L2 (127.134) indicating differential growth responses among isolates in the culture medium. Overall, growth in BG-11 tended to fluctuate more, whereas BBM showed a more consistent pattern in supporting micro-algal growth.

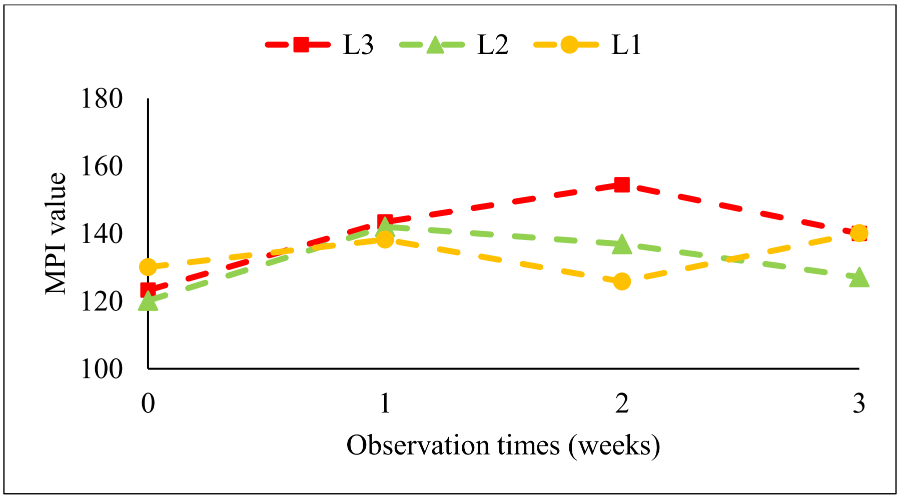

Figure 5. Growth rate of microalgal cultures in BG-11 medium (*Laju pertumbuhan kultur mikroalga dalam medium BG-11*).

Observations of the cultured growth media showed conditions ranging from relatively clear to slightly turbid in day 14, with variations in color intensity (Figure 6). In both BBM and BG-11 media, the color ranged from pale yellow to greenish, indicating microalgal growth at low to moderate cell densities. Overall, microalgal growth was not yet significant at this stage. Differences in turbidity levels and coloration further suggest differential microalgal responses to the type and concentration of the culture media, qualitatively reflecting variations in growth rates.

Figure 6. Culture conditions at day 14 (T2) (*Kondisi kultur pada hari ke-14 (T2)*).

Morphological observations revealed considerable microalgal diversity in both BBM and BG-11 culture media (Figure 7). Genera belonging to Bacillariophyceae, such as *Navicula*, *Nitzschia*, *Triceratium*, and *Synedra*, were the most dominantly identified in the growth media. In addition to Bacillariophyceae, coccoid green algae (Chlorophyceae), including *Chlamydomonas* and *Chlorella*, were observed, along with one representative of Euglenophyceae, *Euglena* sp. This morphological diversity indicates that culture media with limited nutrient concentrations are still capable of supporting the growth of various microalgal groups, particularly from the classes Bacillariophyta, Chlorophyta, and Euglenophyta.

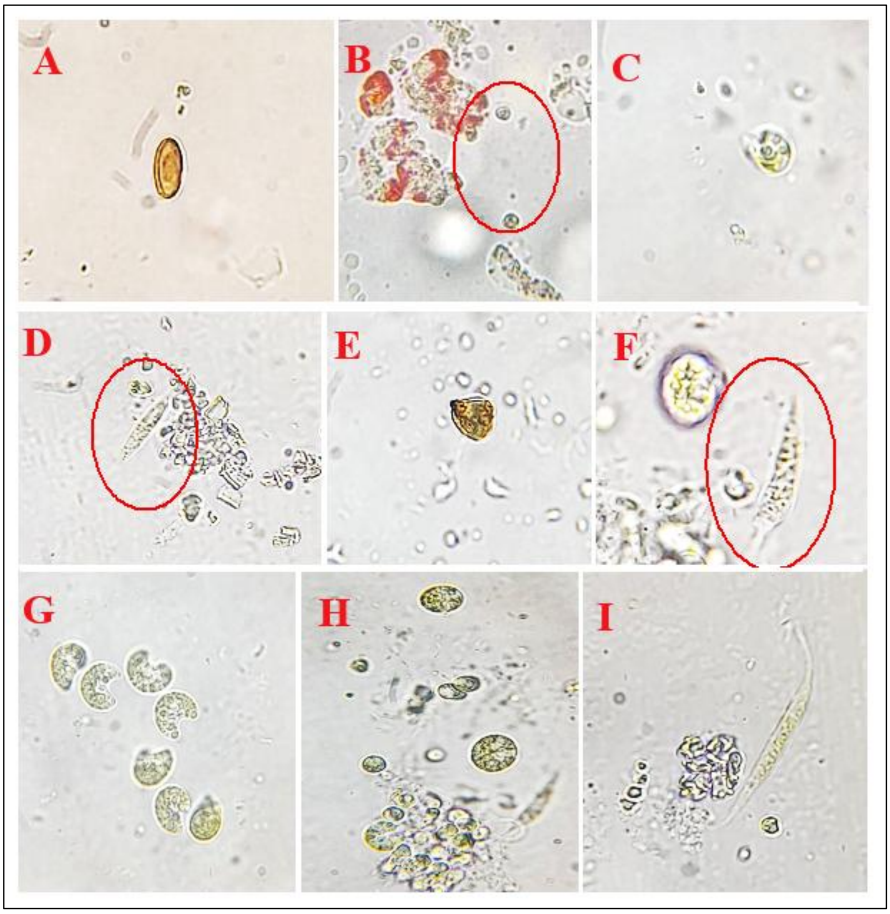

Figure 7. Morphological diversity of microalgae in culture media (*Keanekaragaman morfologis mikroalga dalam media kultur*). Ket. (*Remark*): Observed at 100× magnification (*Diamati pada pembesaran 100×*). (A) *Navicula* sp., (B, H) *Chlorella* sp., (C) *Chlamydomonas* sp., (D) *Nitzschia* sp., (E) *Triceratium* sp., (F) *Synedra* sp., (G) *Euglena* sp., dan (I) *Nitzschia* sp.

DISCUSSION

Diversity and Distribution of Microalgae from Various Water Body

The dominance of Chlorophyceae across all sampling sites indicates that this group possesses high physiological adaptability to varying nutrient conditions. Green algae are known for their opportunistic life strategies and relatively rapid growth rates, enabling them to maintain dominance in waters experiencing moderate to high environmental pressures (Naselli-Flores & Barone, 2009). The dominance of Chlorophyta in aquatic environments was also reported by Keleş and Çelik (2025) in ponds around Balıkesir University, Turkey. They noted that Chlorophyta tend to thrive in waters with high nutrient concentrations, particularly phosphate and nitrogen.

The limited distribution of Cyanophyceae in lakes and drainage systems suggests the presence of specific nutrient conditions that support cyanobacterial growth (Souza *et al*., 2025). Cyanophyceae often function as indicators of eutrophic conditions and anthropogenic pressure due to their sensitivity to nutrient levels, especially phosphorus. Cyanobacteria generally prefer phosphorus-rich waters, particularly genera such as *Microcystis* sp., which possess the ability to adapt to and regulate phosphorus availability (Song *et al*., 2023). In addition to phosphorus management, the capacity to form mucilage under oxidative stress conditions provides cyanobacteria with an adaptive advantage in challenging environments (Whitton & Potts, 2012; Paerl & Otten, 2013).

The relatively limited presence of Zygnematophyceae suggests a narrower habitat preference compared to other microalgal classes. Although this group exhibits more specific habitat preferences, it has been reported to possess high tolerance to certain aquatic conditions and to favor calm waters (Peterson *et al*., 1992; Holzinger *et al*., 2016). This statement aligns with the distribution of Zygnematophyceae observed in lakes and ponds, which are characterized by relatively still water conditions.

In the present study, lake habitats exhibited the highest genus richness among the sampled habitats. High microalgal diversity in campus lake ecosystems has also been reported in Lake Kenanga, Universitas Indonesia, where 14 genera and 20 species were identified (Asharo *et al*., 2023). Lakes serve as strategic growth habitats due to variations in temperature and nutrient levels, minimal physical disturbance, low turbulence, and relative environmental stability (Wetzel *et al*., 2001; Kalff, 2022; and Paerl & Otten, 2013).

The high microalgal diversity observed in campus lakes reflects environmental complexity that allows the formation of diverse ecological niches. Lakes that function as collectors of multiple water sources such as rainfall and runoff from campus activities promote nutrient variability that supports the coexistence of various microalgal taxa. A previous study in Danau Selais, Universitas Riau, reported 18 phytoplankton species and found that the water quality conditions supported phytoplankton development. These conditions included a pH of 6.55–6.63 and a temperature of 28.7–29.1 °C, indicating moderate water fertility (Destiranda *et al*., 2020).

In contrast, the microalgal community structure in ponds indicates stronger environmental selection toward groups with rapid adaptation capabilities. The dominance of Chlorophyceae and Zygnematophyceae without the presence of Cyanophyceae suggests potential phosphorus limitation at these sites. Phosphorus has been shown to influence community shifts and the survival ability of cyanobacteria in aquatic habitats. A study by Wan *et al*. (2019) reported the replacement of *Dolichospermum flos-aquae* by *Microcystis* spp. in Lake Taihu and Lake Chaohu under phosphate-limited conditions. This is because *Microcystis* spp. has a greater ability to hydrolyze organic polymers and particles using cell-surface-bound phosphatases compared to *D. flos-aquae*.

Ponds used for aquaculture and subject to frequent water replacement may create disturbances that limit cyanobacterial growth. Faster physical fluctuations in pond environments tend to favor green algae with short life cycles. This supports the notion that water flow and residence time are primary controlling factors of microalgal composition in small-scale aquatic systems (Wetzel, 2001; Reynolds, 2006).

The phytoplankton communities in both river and drainage channels exhibited low species richness, as only a limited number of taxa were recorded across sites. This suggests a simplified community structure influenced by local environmental conditions, where only a few tolerant groups such as Chlorophyceae, Cyanophyceae, and Zygnematophyceae were able to persist. Irregular water flow and potential waste input allow only stress-tolerant microalgae to persist karena memberikan stress lingkungan akibat Perubahan kondisi fisik dan kimia habitat (Potapova *et al*., 2005; Baattrup-Pedersen *et al*., 2020).

Overall, the observed variation in microalgal diversity and distribution confirms that water body type is a primary determinant of microalgal community structure. Differential responses among microalgal classes to environmental gradients reinforce the role of microalgae as sensitive ecological indicators of habitat change. These findings have important implications for urban water management and the utilization of local microalgae in ecosystem-based biomonitoring and bioremediation strategies. Thus, this study contributes to understanding the ecological mechanisms regulating microalgal distribution in heterogeneous aquatic systems.

Effect of Limited Culture Media on Microalgal Growth

Differences in Mean Pixel Intensity (MPI) values between BG-11 and BBM media indicate that microalgae isolated from peatland aquatic ecosystems can grow under highly limited nutrient compositions. In general, microalgal growth in BG-11 medium produced higher initial MPI values and a more consistent increase up to T2 compared to BBM. This pattern suggests that microalgae exhibited a faster growth response in BG-11 than in BBM.

Although higher MPI values were observed under certain medium conditions, these results may be subject to bias, as changes in color may indicate biomass decline rather than growth alone. While MPI values increased under specific conditions, such increases may lead to misinterpretation. Changes in medium color do not necessarily reflect enhanced growth but may also represent reduced viability or biomass death. This observation is supported by microscopic examination, which revealed smaller microalgal cells and darker coloration in BG-11 medium (Figure 6 A–D). Griffiths *et al*. (2011) reported that colorimetric methods may be biased due to pigment degradation or residual cell debris. Therefore, colorimetric approaches should ideally be complemented with additional measurements such as dry weight, chlorophyll content, and cell turbidity.

In contrast, growth patterns in BBM medium showed more fluctuating responses across samples and incubation times. Although MPI increased on T1, several cultures declined by T2, indicating possible nutrient limitation or physiological stress. Microscopic observations revealed a greater diversity of microalgae with relatively larger cell forms in BBM medium (Figure 7 D–I).

The ability of microalgae to continue growing under nutrient-limited medium conditions suggests adaptive potential to their original environment. Microalgae originating from peat waters with high nutrient fluctuations generally exhibit greater nutrient-use efficiency (Uda *et al*., 2024).

Overall, observations of microalgae cultured in BBM and BG-11 media indicate that microalgae derived from peat-associated aquatic ecosystems can adapt to nutrient-limited conditions. Differences in growth performance between BG-11 and BBM confirm that culture medium selection plays a critical role in determining microalgal growth dynamics. Growth measurement using the MPI technique may serve as an alternative solution for laboratories with limited instrumentation; however, it requires complementary supporting data. These findings have important implications for low-cost microalgal cultivation strategies, particularly in the exploration of local microalgae and the optimization of simple media for biotechnological and environmental applications.

CONCLUSION

This study demonstrates that the investigated urban and semi-urban waters can support the presence and growth of diverse microalgal taxa, including Cyanobacteria, Chlorophyceae, and Zygnematophyceae, with green algae dominating most water body types. The distribution of microalgal communities varied among water types, reflecting the influence of environmental conditions on community structure. The diversity of morphological forms and growth types indicates the adaptive potential of local microalgae to heterogeneous environmental conditions. Culture results showed that microalgae were able to grow in nutrient-limited media. The use of mean pixel intensity

(MPI) values has potential for application in microalgal growth measurement, although it should be supported by additional data. Overall, these findings emphasize that local microalgae have strong potential for development in simple and low-cost culture systems, even under limited nutrient conditions.

LIMITATION

We acknowledge that this study has several limitations, including ecological measurements and the limited number of cultured samples due to technical constraints. We therefore recommend that future studies include more comprehensive ecological assessments and employ more advanced and integrated analytical techniques to better observe growth patterns and species composition.

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AUTHOR CONTRIBUTIONS

F.A.: Conceptualization; Methodology; Investigation; Formal analysis; Data curation; Visualization; Writing – original draft preparation. D.Z.: Conceptualization; Methodology; Validation; Resources; Supervision; Writing – review & editing; Project administration. Authors have read and agreed to the published version of the manuscript.

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