AL-KAUNIYAH: Jurnal Biologi, 19(2), 2026, 363-375
Website: http://journal.uinjkt.ac.id/index.php/kauniyah
P-ISSN: 1978-3736, E-ISSN: 2502-6720

COMMUNITY STRUCTURE OF MICROALGAE IN URBAN SMALL LAKES (BABAKAN, KENANGA, AND PUSPA) UNDER ANTHROPOGENIC NOISE VARIATION: IMPLICATIONS FOR BIOFUEL RAW MATERIAL

STRUKTUR KOMUNITAS MIKROALGA DI SITU-SITU AREA URBAN (BABAKAN, KENANGA, DAN PUSPA) DENGAN VARIASI KEBISINGAN ANTROPOGENIK: IMPLIKASI SEBAGAI BAHAN BAKU BIOFUEL

Rubiantin Mesha Nauli Tambunan[1], Nining Betawati Prihantini[1]*, Santoso Soekirno[2], Nasruddin[3]
[1]*Department of Biology, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok 16424, Indonesia*
[2]*Department of Physics, Faculty of Mathematics and Natural Sciences, Universitas Indonesia, Depok 16424, Indonesia*
[3]*Department of Mechanical Engineering, Faculty of Engineering, Universitas Indonesia, Depok 16424, Indonesia*
**Corresponding author:* nining@sci.ui.ac.id

Submitted: 22 October 2025; Revised: 24 January 2026; Accepted: 12 May 2026

Abstract

The global energy transition relies on renewable solutions such as microalgae. However, the diversity of microalgae in urban freshwaters, especially how anthropogenic noise affects them, remains unexplored. Our study explores three small lakes in Greater Jakarta—Babakan (South Jakarta), Puspa, and Kenanga (Universitas Indonesia, Depok, West Java)—that are becoming more exposed to anthropogenic noise, an evolving stressor with uncertain ecological effects on microalgae. Microalgae were identified from water samples collected from Babakan, Kenanga, and Puspa lakes, which had sound levels of -69.37 dB, -81.49 dB, and -99.43 dB, respectively. The results show that Kenanga Small Lake has the highest diversity (H' 2.44), while Puspa Small Lake has the highest dominance (D = 0.16) and evenness (E = 0.88). The "silent" Puspa Lake has the highest lipid percentage, which was 51.66%. While all environmental factors are interconnected to affect microalgal community structure and lipid percentage, these data point to a possible link between lower noise levels and better lipid yields, implying that indigenous microalgae from calmer urban contexts could be a feasible source of sustainable biofuel production.

Keywords: Anthropogenic noise; Biofuel; Community structure; Lipid; Microalgae

Abstrak

Transisi energi global bergantung pada solusi terbarukan seperti mikroalga. Keanekaragaman mikroalga di perairan tawar perkotaan, terutama bagaimana kebisingan antropogenik memengaruhinya, masih belum banyak dieksplorasi. Penelitian kami mengeksplorasi tiga situ di Jabodetabek—Babakan (Jakarta Selatan), Puspa, dan Kenanga (Universitas Indonesia, Depok, Jawa Barat)—yang semakin terpapar kebisingan antropogenik, tekanan ekologis yang terus berkembang dengan dampak ekologis terhadap mikroalga yang belum diketahui secara pasti. Mikroalga diidentifikasi secara morfologis dari sampel air yang diambil dari Situ Babakan, Kenanga, dan Puspa. Tingkat kebisingan masing-masing situ yaitu -69,37 dB, -81,49 dB, dan -99,43 dB. Hasil penelitian menunjukkan bahwa Situ Kenanga memiliki keanekaragaman tertinggi (H' = 2,44), sedangkan Situ Puspa memiliki dominansi (D= 0,16) dan kemerataan (E= 0,88) tertinggi. Situ Puspa yang dianggap sunyi atau tenang memiliki persentase lipid tertinggi, yaitu 51,66%. Meskipun semua faktor lingkungan saling terkait dalam memengaruhi struktur komunitas mikroalga dan persentase lipid, hasil penelitian menunjukkan kemungkinan adanya hubungan antara tingkat kebisingan yang lebih rendah dengan persentase lipid yang lebih tinggi. Hal tersebut menguatkan dugaan bahwa mikroalga indigenous *dari daerah urban yang lebih tenang dapat menjadi sumber produksi biofuel berkelanjutan.*

***Kata Kunci**: Biofuel; Kebisingan antropogenik; Lipid; Mikroalga; Struktur komunitas*

Permalink/DOI: http://dx.doi.org/10.15408/kauniyah.v19i2.47095

INTRODUCTION

Freshwater habitats, such as lakes and small lakes (referred to as "*situ*" in the local context), are essential to urban areas. These types of water bodies provide essential ecosystem services, such as water regulation (Teurlincx et al., 2019), and can also be used for recreational activities (Henny & Mutia, 2014). Small lakes in urban areas preserve a significant degree of biodiversity, despite environmental stresses driven by urbanization. Fish (Petriki & Bobori, 2024), aquatic plants (Tan et al., 2024), zooplankton, bacteria, and microalgae (Pikoli et al., 2019; Hendrayanti et al., 2023) are among the many species living in lakes or small lakes. The resilience of this ecosystem shows how tolerant the inhabitants are to anthropogenic stressors.

One key group of organisms that lives in the small lake, including urban areas, is microalgae. Microalgae are a non-taxonomic group of photosynthetic microorganisms (Barsanti & Gualtieri, 2023). This group of organisms plays an essential role as the primary producers in the ecosystem. It forms the base of the aquatic food web and influences nutrient cycles (Yan et al., 2023). Several microalgal species are known to frequently dominate urban small lakes. Domination may happen because those species are developing unique physiological adaptations under unfavorable conditions. For example, some microalgae in the *Chlorophyta* division have developed adaptive mechanisms to cope with changes in nutrient availability (Hamdhani et al., 2024). Specific strains have been studied and shown to adapt to and even effectively remediate some contaminants, including heavy metals (Binda et al., 2022; Pandey et al., 2023) and microplastics (Guo et al., 2024). A comprehensive understanding of these ecological roles and adaptations is required for optimal management and use of urban aquatic resources.

Anthropogenic noise is one form of anthropogenic stressors. It is an increasingly pervasive and often overlooked factor in ecosystem studies, especially in studies of microbial habitats (Colbert, 2020). Urban aquatic habitats, especially lakes ("*situ*"), are subjected to numerous sources of noise (Bolgan et al., 2016). The primary sources are land and water transportation (Valenzisi et al., 2024), neighboring construction operations (Wang et al., 2022), industry and urbanization activities (Kuehne et al., 2013), and water recreation (Henny & Mutia, 2014). The detrimental effects of anthropogenic noise have been studied on larger aquatic animals, such as marine mammals and fish. Those studies show disruptions in communication, feeding behavior, and reproduction. However, its impact on microorganisms, especially in their natural habitats, remains largely unknown (Kuehne, 2013; Prosnier, 2024).

Previous laboratory-scale studies provide some preliminary information on how microalgae respond to sound. According to these studies, exposure to various sound frequencies and intensities can either stimulate or hinder microalgal growth, depending on the strain (Cai et al., 2014; Cai et al., 2016; Christwardana & Hadiyanto, 2017; Carpio et al., 2015; Tambunan et al., 2021). Some microalgae strains, such as *Chlorella* DPK-01 (Tambunan et al., 2020) and *Scenedesmus* SBG-01 (Tambunan & Prihantini, 2023) (*Chlorophyta*), show increased growth rates when exposed to certain music, whereas other strains, such as *Synechococcus* HS-9 (*Cyanobacteria*), exhibit the opposite effect (Santoso et al., 2020b). This physiological reaction is not limited to microalgal growth. Sound waves have been linked to stress-induced lipid accumulation in some strains, which is an important factor for biofuel production.

Research on microalgae's potential as a sustainable biofuel has emerged over the last two decades (Carpio et al., 2015; Prihantini et al., 2020; Tambunan et al., 2024; Rajan & Gaurav, 2023). Microalgae are highly promising for biofuel production due to their rapid growth rates, high biomass productivity, and ability to thrive on non-arable land without competing with food crops. Most of these studies focused on maximizing biomass and lipid production by optimizing physical (Ardiansyah et al., 2020; Santoso et al., 2020a) and chemical parameters (Yanti et al., 2021; Prihantini et al., 2024). However, the impact of acoustic waves, which would exist in an industrial setting, has been generally overlooked.

Previous studies in Indonesia have discovered microalgal biodiversity in urban small lakes such as Situ Babakan, Situ Puspa, and Situ Kenanga. These studies found that *Cyanobacteria* predominated in all three locations. However, there were also significant differences in community structure that were linked to variations in environmental factors (Prihantini et al., 2010; El Amin, 2023; Maulana, 2023). To this day, comparison of the microalgal communities in these three lakes, while specifically considering the gradient of anthropogenic noise they are exposed to, has not been done.

Therefore, this study was done to (1) examine the community structure of microalgae in three urban small lakes, which are Puspa, Kenanga, and Babakan; (2) analyze the effect of anthropogenic noise on microalgae diversity as well as its dominance, and (3) determine the implications of these findings for the utilization of microalgae as a raw material for biofuel production.

MATERIALS AND METHODS

Sampling Location

Sampling was conducted in three small urban lakes (situ) located in the Jabodetabek metropolitan area: Babakan Small Lake (Situ Babakan; South Jakarta), Kenanga Small Lake (Situ Kenanga; West Java), and Puspa Small Lake (Situ Puspa; West Java). The locations of the lakes are shown in Figure 1, with Situ Babakan marked by letter (a), Situ Kenanga by letter (b), and Situ Puspa by letter (c). Each sampling point (Inlet, Midlet, and Outlet) was also marked in the figure.

Figure 1. Sampling locations: Situ Babakan (a), Situ Kenanga (b), and Situ Puspa (c) (Source: Google Earth with Modifications)

Sampling and Environmental Data Collection

A purposive sampling method was used to collect microalgae from the oxic zone of the three urban small lakes. Sampling was performed in the morning (9–11 AM) to target microalgae at the water surface. Samples were collected using a plankton net with a 20 µm mesh size, horizontally thrown 7.5 m from the sampling raft. Sampling points were strategically chosen based on the hydrology of each small lake. Situ Puspa and Situ Kenanga have three sampling points each (inlet, midlet, and outlet). Situ Babakan, having two inlets, had four sampling points: inlet 1 (ISTN), inlet 2 (Mangga Bolong), midlet, and outlet.

A total of six replicates were collected from each sampling point. The first three replicates were stored as fresh samples. The remaining three were preserved by 4% formalin immediately on-site for later morphological identification and community structure analysis. Environmental parameters were measured at each sampling location, including water temperature (°C), pH level, weather conditions, depth (cm), and dissolved oxygen (mg/L) concentration (using a YSI Model 33 SCT DO meter). The geographic position of each site was recorded with a GPS. Noise level around the sampling area was also measured by recording sound for 15 minutes at each sampling point. It was done with a mobile phone's voice recorder placed right above the water surface. The resulting audio files were analyzed using Audacity software to determine the noise level and dominant sound frequency of each small lake.

Microalgae Identification and Community Structure Analysis

Microalgae identification and counting were performed according to the methods used by Prihantini et al. (2020). A Pasteur pipette was used to draw the samples from the bottles. The sample was dropped onto the object glass for up to 0.04 mL. The sample was then covered with a cover slip. The covered sample was then analyzed using a light microscope. Bellinger and Sigee (2015) were used as references to identify the observed microalgae. Observed microalgae were then counted using the subsample method (Prihantini et al., 2020) and photographed using a mobile camera.

The community structure of microalgae in each small lake was analyzed based on identification and cell-counting results. Ecological indices, such as Diversity (H'), Dominance (D), and Evenness (E), were calculated. The Diversity Index (H') value is obtained by dividing the n_i value (the number of individuals of the i-th species) by the N value (the total number of individuals), which is then multiplied by the ln of the quotient of the n_i value and the N value (Stiling, 2001). The Dominance Index (D) is obtained by summing the squares of the ni value (the number of individuals of the i-th species) by the N value (the total number of individuals) (Magurran, 2005). Additionally, the Evenness Index (e) is used to evaluate the uniformity of species distribution based on the Shannon-Weiner diversity value. This index is calculated by dividing the H’ value obtained from each sampling point by the total H’ value (Odum, 2004). These ecological indices are then presented in the form of a graph to be compared with the sound level.

Biomass Harvesting and Lipid Extraction

The biomass harvesting method was also performed according to the methods used by Prihantini et al. (2020). Approximately 10 L of water was directly collected—without a plankton net—from each small lake. Those water samples were then processed using the Ultrasound Harvesting Module (UHM), which utilizes acoustic waves to flocculate microalgal cells (Ardiansyah et al., 2020). The harvested biomass was then dried in an oven at 40 °C for 36 hours, and the resulting dry biomass was weighed to determine the dry biomass weight.

Lipid extraction was done on the dried biomass using a modified Bligh and Dyer (1959) method, following Tambunan et al. (2024). A 30 mL mixture of methanol and chloroform (2:1 v/v) was added to the dry biomass. The mixture was then sonicated for 10 minutes. Subsequently, a 15 mL mixture of distilled water and chloroform (1:1 v/v) was added, and the mixture was sonicated again for another 10 minutes. The solution was then left to stand, allowing it to separate into two layers. The bottom chloroform layer containing the extracted lipids was transferred to a petri dish. This sample was dried at 40 °C until the solvent had evaporated. The final weight was used to calculate the lipid percentage. Lipid percentage was calculated by dividing dry lipid weight by dry biomass weight (Li et al. 2008; Tambunan et al., 2024). These total lipid percentages are then presented in the form of a graph to be compared by the sound level.

RESULTS

Environmental Data at the Sampling Location

The environmental conditions of the three small lakes—Babakan, Kenanga, and Puspa—were characterized by measuring several key parameters. Data on surrounding and water temperature, depth, dissolved oxygen (DO), and sound level were collected at various sampling sites within each lake to assess spatial variations. Table 1 presents the environmental data collected during the study. The highest value of each parameter is highlighted in peach.

Table 1. Environmental data collected at the sampling location

Location		Temperature (°C)		Depth (cm)	Dissolved oxygen (mg/L)	Sound level (dBFS)	pH	Weather condition
Small lake	Sampling site	Surroundings	Water					
Babakan	Inlet 1	31.00	31.90	125.00	10.70	-73.23	4.0	Cloudy
	Inlet 2	32.00	32.40	75.00	9.54	-66.88	4.0	
	Midlet	32.00	32.80	155.00	6.81	-69.59	4.0	
	Outlet	33.00	34.30	149.00	6.90	-67.79	4.0	
Kenanga	Inlet	33.00	33.90	57.00	6.92	-91.73	4.0	Cloudy
	Midlet	33.00	33.00	164.00	6.02	-88.09	5.0	
	Outlet	33.00	33.50	181.00	6.01	-64.64	4.0	
Puspa	Inlet	30.00	31.20	84.50	7.45	-93.22	4.5	Cloudy
	Midlet	31.00	32.30	24.00	6.08	-103.08	4.5	
	Outlet	32.00	35.50	169.00	6.02	-101.99	4.0	

Based on Table 1, variations in key parameters were observed across the sampling locations. Babakan Small Lake demonstrated the highest average dissolved oxygen (DO) concentration at 8.49 mg/L, significantly greater than Kenanga (6.32 mg/L) and Puspa (6.52 mg/L). The average water temperature was highest in Kenanga Small Lake (33.50 °C), compared to Puspa (33.30 °C) and Babakan (32.70 °C). Kenanga Small Lake was also the greatest in terms of average depth, which is 178.33 cm; followed by Babakan (126.33 cm) and Puspa (124.67 cm). The weather conditions during our sampling time in these 3 small lakes were cloudy. Additionally, the pH level in all small lakes is slightly acidic, which are ranging from 4 to 5.

To interpret the acoustic environment accurately, sound levels were analyzed using the Decibels Full Scale (dBFS) standard. In this digital scale, 0 dB represents the maximum recording ceiling. Therefore, all measured values are expressed as negative numbers relative to this peak. The lowest average level was recorded in Puspa Small Lake (-99.43 dBFS), representing the noise floor of the recording system and a baseline of minimal acoustic activity. In contrast, Babakan Small Lake (-69.37 dBFS) and Kenanga (-81.49 dBFS) exhibited significantly higher acoustic energy.

Microalgae Identification and Community Structure

The abundance of microalgae was quantified to assess the biological characteristics of the three small lakes. The average cell counts (cells/L) for various microalgae genera were determined at Babakan, Kenanga, and Puspa lakes. Table 2 provides a comprehensive list of all identified microalgae genera and their respective abundance values at each sampling location.

The abundance of microalgae genera varied among the three small lakes. *Spirulina* was the most abundant in Babakan Small Lake (73,232.4 cells/L), while *Arthrospira* was the most abundant in Kenanga Small Lake (68,686.8 cells/L). In Puspa Small Lake, *Spirulina* also had the highest abundance (37,037 cells/L), followed by the unidentified coccoid green algae (30,909.7 cells/L). The photomicrograph of these microalgae can be seen in Figure 2.

Several genera, such as *Pediastrum* and *Scenedesmus,* were found in various forms across the sampling sites. *Pediastrum* was represented by five distinct forms (*Pediastrum* 1–5), and their abundances varied across the three lakes. Similarly, *Scenedesmus* was found in three forms (*Scenedesmus* 1–3), with their abundance differing among the lakes. The distinctive forms of *Pediastrum* and *Scenedesmus* are shown in Figure 3.

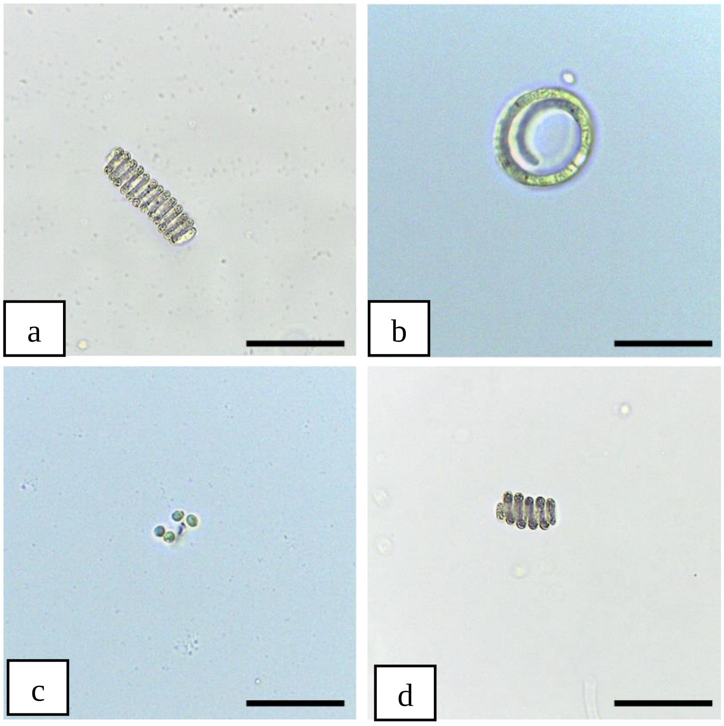

Figure 2. Photomicrograph of *Spirulina* from Babakan (a), *Arthrospira* from Kenanga (b), unidentified coccoid green algae (c), and *Spirulina* from Puspa (d). ▬▬ : 50 µm

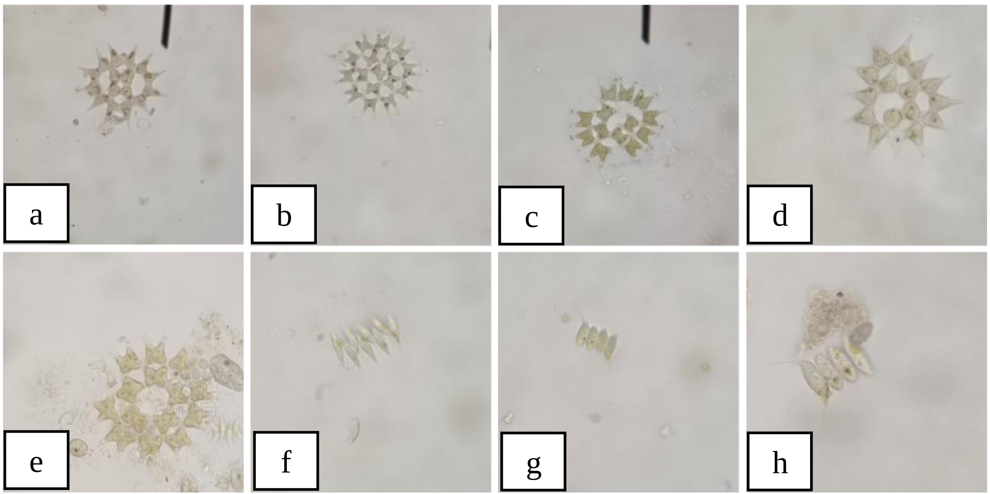

Figure 3. Photomicrograph of colonial microalgae with different morphological forms: *Pediastrum* 1 from Babakan (a), *Pediastrum* 2 from Puspa (b), *Pediastrum* 3 from Puspa (c), *Pediastrum* 4 from Babakan (d), *Pediastrum* 5 from Kenanga (e), *Scenedesmus* 1 from Kenanga (f), *Scenedesmus* 2 from Puspa (g), and *Scenedesmus* 3 from Babakan (h). Pictures not to scale

The diversity and evenness of microalgae communities were analyzed at different sampling points within each of the three Small Lakes, with the highest values for each metric highlighted in peach (Table 3). In Babakan Small Lake, the microalgae community showed a mean Diversity Index (H′) of 2.38, with individual sampling points ranging from 1.83 to 2.68. The corresponding mean Dominance Index (D) was 0.14, and the mean Evenness Index (E) was 0.77. The community in Kenanga Small Lake had a mean Diversity Index (H′) of 2.44, with individual values ranging from 2.36 to 2.49. Its mean Dominance Index (D) was consistently low at 0.12, and the average Evenness Index (E) was 0.81. Finally, Puspa Small Lake exhibited a mean Diversity Index (H′) of 2.33, with values from 2.16 to 2.50. Its mean Dominance Index (D) was 0.16, slightly higher than the other two Small Lakes, while its average Evenness Index (E) was the highest at 0.88. A summary of the average values for each location revealed that Babakan had an average H′ of 2.38, D of 0.14, and E of 0.77;

Kenanga had an average H′ of 2.44, D of 0.12, and E of 0.81; and Puspa had an average H′ of 2.33, D of 0.16, and E of 0.88.

Table 2. Microalgae abundance (cells/L) in each small lake

Microalgae genera	Average of microalgae abundance (N) value (cells/L)		
	Babakan	Kenanga	Puspa
Actinastrum	505.1	7474.7	5387.2
Anabaena	10101	18181.8	0
Ankistrodesmus	0	6060.6	673.4
Ankyra	1515.2	0	0
Apanothece	505.1	2020.2	1346.8
Arthrospira	52020.2	68686.8	26942.7
Aulacoseira	5555.6	2693.6	0
Chlorococcum	4545.4	0	0
Chroococcus	1515.2	0	0
Crucigenia	0	2693.6	0
Cruciginella	0	2020.2	0
Cyclotella	2020.2	5387.2	6734.4
Eudorina	2020.2	8969.5	5387.2
Euglena	3030.3	0	1346.8
Gonium	2020.2	7474.7	3373.7
Limnothrix	3030.3	0	673.4
Melosira	2525.3	0	3367
Merismopedia	4040.4	17508.4	14848.8
Microcystis	0	2020.2	0
Oscillatoria	2020.2	0	3367
Pandorina	1010.1	4040.4	3373.7
Pediastrum 1	6060.6	2020.2	0
Pediastrum 2	9696.9	2020.2	2693.6
Pediastrum 3	9191.9	6734.4	5387.2
Pediastrum 4	3030.3	4040.4	0
Pediastrum 5	7070.7	673.4	673.4
Phacus 1	9696.9	8080.8	2693.6
Phacus 2	3030.3	5387.2	6060.6
Phacus 3	505.1	0	0
Plankthotrix 1	20707	0	0
Plankthotrix 2	3030.3	0	2693.6
Planktothrix 3	6565.7	0	0
Pseudanabaena	2525.3	3367	0
Scenedesmus 1	2020.2	14141.4	9696.9
Scenedesmus 2	2020.2	11414.1	6734.4
Scenedesmus 3	2020.2	2020.2	0
Spirulina	73232.4	70707	37037
Tetraspora	505.1	8969.5	1346.8
Trachelomonas	0	673.4	673.4
Unidentified coccoid green	23737.4	39039	30999.7

Our analysis of the community structure has shown an interesting finding when correlated with the measured sound levels (Figure 4). Kenanga Small Lake, with an intermediate noise level (-81.49 dB), showed the highest diversity, while Puspa Small Lake, the quietest of the three (-99.43 dB), had the highest dominance (D= 0.16) and evenness (E= 0.88). The dominance of specific genera like *Spirulina* and *Arthrospira* in the noisier small lakes (Babakan and Kenanga) suggests that these organisms may be more resilient or adaptable to such stressors.

Table 3. Ecological indices of Babakan, Kenanga, and Puspa Small Lake

Location	Sampling point	Diversity index (H′)	Dominance index (D)	Evenness index (E)

Babakan	Inlet 1	2.68	0.08	0.81
	Inlet 2	1.83	0.27	0.64
	Midlet	2.52	0.10	0.80
	Outlet	2.47	0.11	0.81
Kenanga	Inlet	2.36	0.13	0.81
	Midlet	2.47	0.12	0.80
	Outlet	2.49	0.12	0.82
Puspa	Inlet	2.33	0.16	0.88
	Midlet	2.16	0.19	0.84
	Outlet	2.50	0.12	0.92

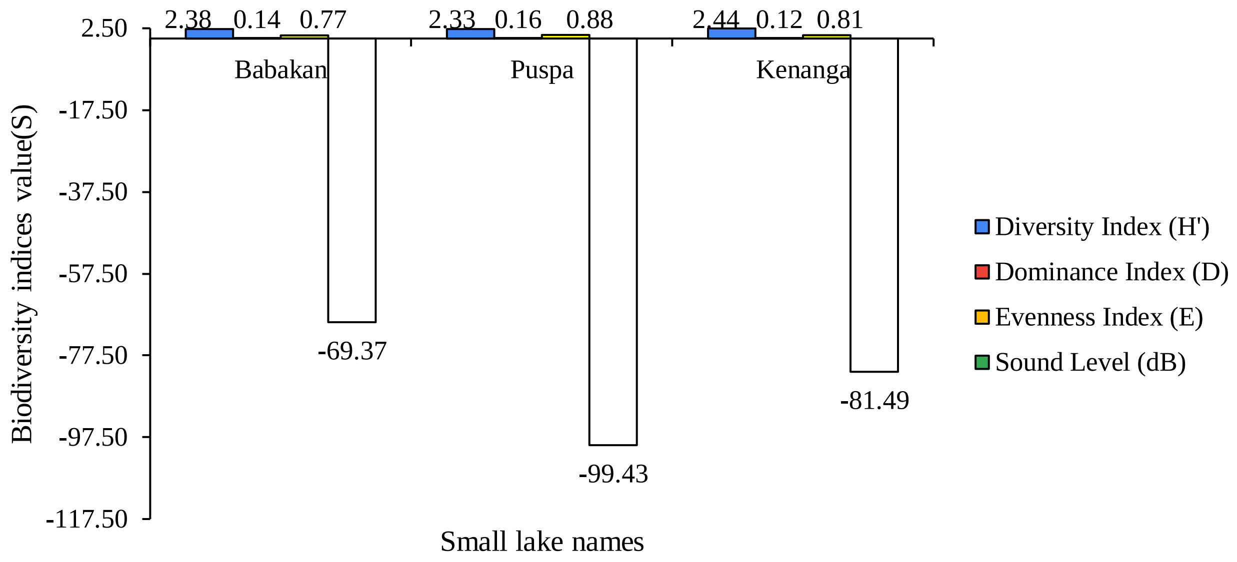

Figure 4. Graph of the connection between community structure and sound level values

Lipid Percentage

Analysis of the microalgae biomass from the three small lakes revealed slight variations in their lipid content. It can be seen from the graph in Figure 5. The highest lipid percentage was observed in samples from Puspa Small Lake, reaching 51.66%. This was followed closely by the microalgae from Kenanga Small Lake, which had a lipid percentage of 50.18%. The lowest lipid percentage was found in the microalgae from Babakan Small Lake, at 46.96%. A key finding from this study is the relationship between anthropogenic noise and the percentage of microalgal lipids. Microalgae biomass from Puspa Lake, with the lowest sound intensity, has the highest lipid content (51.66%). This inverse relationship suggests that quieter environmental conditions may be more conducive to lipid accumulation within these microbial communities.

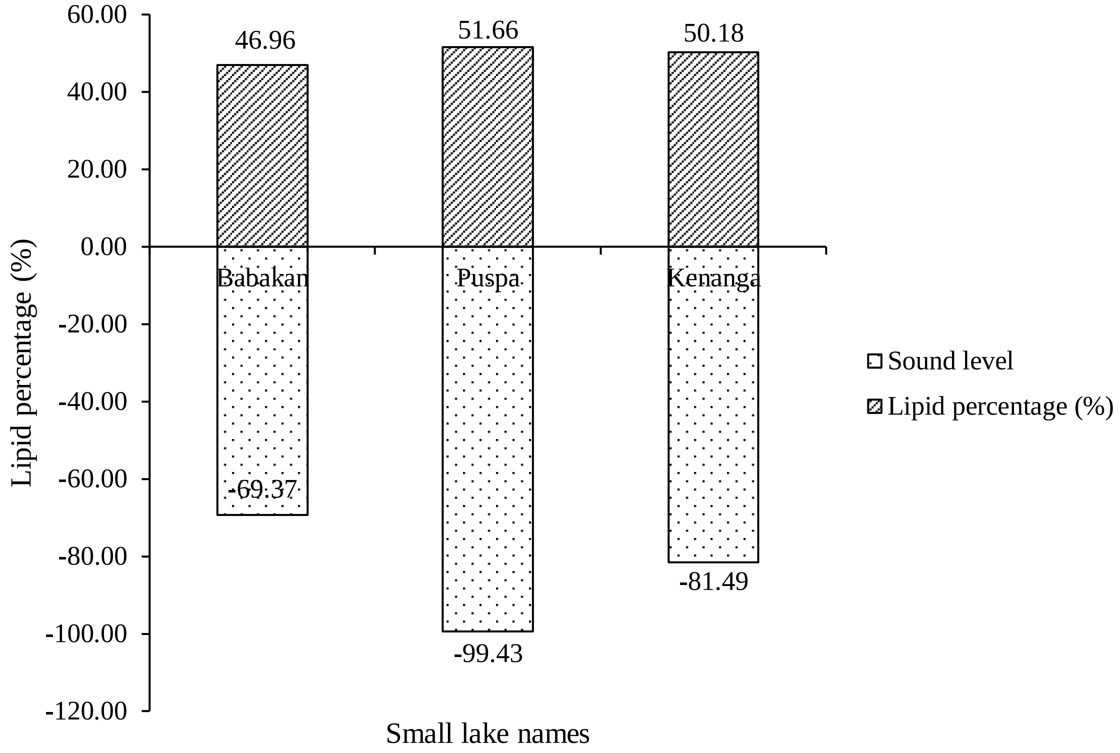

Figure 5. Graph of the connection between lipid percentage and sound level values

DISCUSSION

This study examines the complex correlation between microalgal communities and environmental factors, especially anthropogenic noise in urban small lakes. Specifically, it focuses on how anthropogenic noise as an environmental stressor may impact the potential of microalgae as a biofuel raw material. Environmental parameters observed across Babakan, Kenanga, and Puspa small lakes show that distinct habitats likely drive seasonal shifts in microalgal community structures. The significantly higher dissolved oxygen (DO) levels in Babakan (8.49 mg/L) suggest a higher photosynthetic rate compared to the deeper, warmer waters of Kenanga. Furthermore, the slightly acidic pH levels (4–5) across all sampling sites, alongside the cloudy weather during sampling, indicate a growth environment that may select for specific microalgae that can tolerate those conditions. Variations of these physical factors, such as the elevated temperatures in Kenanga (33.50 °C), may act as critical secondary stressors alongside anthropogenic noise. This condition potentially alters the metabolic pathways responsible for lipid production in microalgae. Consequently, these abiotic factors must be considered as integral components of the ecological setting when evaluating the overall potential of microalgae from urban small lakes as a sustainable biofuel raw material.

In order to accurately interpret the acoustic environment and avoid data misinterpretation, sound levels were measured using the Decibels Full Scale (dBFS) standard. While sound pressure is often measured on a logarithmic scale, with 0 dB representing the human hearing threshold (Beranek & Mellow, 2019), we analyzed our recorded sound levels on a digital scale. In digital terms, the value of 0 dB is considered the maximum recording ceiling. As a result, all measured values are displayed negatively in relation to this peak. Negative values on the dBFS scale do not signify the absence of sound, but rather the intensity of acoustic energy in accordance with the digital maximum. A value that is closer to zero indicates a higher sound intensity (Kagan, 2025).

Our recorded levels in Babakan (-69.37 dBFS), Kenanga (-81.49 dBFS), and Puspa (-99.43 dBFS) show varying levels of anthropogenic pressure in each sampling site. Based on a logarithmic scale (Kagan, 2025; Beranek & Mellow, 2019), Kenanga is approximately 62 times noisier than Puspa, while Babakan exhibits an acoustic intensity roughly 1,000 times greater than Puspa and 16 times greater than Kenanga. These findings are in accordance with intense human activity in Babakan and Kenanga, compared to the relatively quiet conditions in Puspa. The high acoustic energy recorded in Babakan suggests a state of persistent physical agitation. Unlike humans, microalgae are highly sensitive to subtle vibrations and pressure waves. Such acoustic pressure can induce physical stress, potentially compromising cell membrane integrity or reducing photosynthetic efficiency, similar to responses observed in higher plants (Chauhan et al., 2023). Consequently, prolonged exposure may force a metabolic shift, diverting energy from growth toward survival mechanisms, such as lipid synthesis (Shi et al., 2020). Our findings offer new perspectives into microalgae ecosystems in urban lakes. We discovered significant differences in environmental factors, microalgal communities, and lipid percentages among the three lakes. It suggests a potential connection between various noise levels and microalgal lipid percentage. This connection has significant implications for biofuel production.

Certain microalgae species can develop unique physiological adaptations to unfavorable conditions (Hamdhani et al., 2024; Guo et al., 2024). For instance, the dominance of specific genera, such as *Spirulina* and *Arthrospira,* in the noisier environments (Babakan and Kenanga) suggests that these organisms possess higher resilience or adaptability to such acoustic stressors. Furthermore, the presence of multiple morphological forms of genera such as *Pediastrum* and *Scenedesmus* across all three lakes indicates a high degree of phenotypic plasticity. These colonial forms may represent an adaptive strategy to thrive in a range of conditions, including varying levels of anthropogenic noise. Coloniality can offer advantages such as defense against grazing pressure (Wang et al., 2022), improved nutrient uptake, or increased resistance to environmental stresses (Lin et al., 2020). The widespread presence and morphological diversity of these genera, even in the most anthropogenically-impacted lake, reinforces the idea that some microalgae are highly tolerant to urban stressors, including acoustic disturbances.

This finding is in line with laboratory-scale studies indicating that sound waves can trigger stress-related lipid accumulation in several microalgae strains (Ren et al., 2019; Wei et al., 2022; Helfield et al., 2016). Although other environmental parameters, such as dissolved oxygen (DO) and temperature, also affect the lipid, the difference in noise levels across the three small lakes provides an interesting context for exploring that connection. The higher lipid percentage in the "silent" lake could be a response to environmental stress caused by other factors. Microalgae are known to produce higher amounts of lipids in unfavorable conditions (Han et al., 2016; Anam et al., 2021). This shows a possible new approach for selectively cultivating indigenous microalgae from small lakes in quieter urban areas for sustainable biofuel production. Further studies are needed to identify these specific strains and determine their lipid-producing ability under laboratory conditions.

CONCLUSION

In conclusion, this study demonstrates that anthropogenic noise impacts microalgal communities in urban small lakes. Specifically, a correlation was observed between lower noise levels and higher lipid percentages, identifying microalgae from quieter environments—such as Puspa Small Lake—as promising raw materials for biofuel. However, as this is a preliminary investigation, large-scale industrial applications require a comprehensive analysis of additional ecological and physicochemical factors to ensure consistent lipid yields. Future studies should also be done to know the overall bioenergy potential of these strains beyond lipids. Investigating the carbohydrate profiles of microalgae biomass from Kenanga, Puspa, and Babakan small lakes could reveal their suitability for biohydrogen production, thereby establishing them as a sustainable biofuel raw material.

ACKNOWLEDGEMENTS

This study was part of the research supported by Hibah PUTI Q1 no. PKS-202/UN2.RST/HKP.05.00/2025 to Prof. Dr. Dra. Nining Betawati Prihantini, M.Sc. Fiscal year: 2025—2026.

REFERENCES

Anam, K., Rahman, D. Y., Hidhayati, N., Rachmayati, R., Susilaningsih, D., … Apriastini, M. (2021). Lipid accumulation on optimized condition through biomass production in green algae. *IOP Conference Series: Earth and Environmental Science, 762*(1), 012075. doi: 10.1088/1755-1315/762/1/012075.

Ardiansyah, S. R., Orlando, A. M., Rahman, A., Nasruddin., & Prihantini, N. B. (2020). Preliminary design of microalgal biomass harvesting module using ultrasound wave trapping principle. *International Conference on Trends in Material Science and Inventive Materials: ICTMIM 2020, 2259,* 030015. doi: 10.1063/5.0013545.

Barsanti, L., & Gualtieri, P. (2023). *Algae: Anatomy, biochemistry, and biotechnology (3rd ed.)*. Boca Raton: CRC Press.

Bellinger, E. G., & Sigee, D. C. (2015). *Freshwater algae: Identification, enumeration, and use as bioindicators*. West Sussex: John Wiley & Sons.

Beranek, L., & Mellow, T. (2019). Introduction and terminology. *Acoustics: Sound fields, transducers and vibration* (pp. 1–23). https://doi.org/10.1016/b978-0-12-815227-0.00001-7

Binda, G., Faccini, D., Zava, M., Pozzi, A., Dossi, C., Monticelli, D., & Spanu, D. (2022). Exploring the adsorption of Pb on microalgae-derived biochar: A versatile material for environmental remediation and electroanalytical applications. *Chemosensors*, *10*(5), 168. doi: 10.3390/chemosensors10050168.

Bligh, E. G., & Dyer, W. J. (1959). A rapid method of total lipid extraction and purification. *Canadian Journal of Biochemistry and Physiology*, *37*(1), 911-917.

Bolgan, M., Picciulin, M., Codarin, A., Fiorin, R., Zucchetta, M., & Malavasi, S. (2016). Is the Venice Lagoon noisy? First passive listening monitoring of the Venice Lagoon: Possible effects on the typical fish community. *Advances in Experimental Medicine and Biology*, *875*, 83-90.

Cai, W., He, H., Zhu, S., & Wang, N. (2014). Biological effect of audible sound control on mung bean (*Vigna radiata*) sprout. *BioMed Research International*, *2014*, 1-6.

Cai, W., Dunford, N. T., Wang, N., Zhu, S., & He, H. (2016). Audible sound treatment of the microalgae *Picochlorum oklahomensis* for enhancing biomass productivity. *Bioresource Technology*, *202*, 226-230.

Carpio, R. B., De Leon, R. L., & Martinez-Goss, M. R. (2015). Growth, lipid content, and lipid profile of the green alga, *Chlorella vulgaris* Beij., under different concentrations of Fe and CO_2. *Journal of Engineering Science and Technology, Special Issue on SOMCHE 2014 and RSCE 2014 Conference,* 19-30.

Chauhan, J., Prathibha, M. D., Singh, P., Choyal, P., Mishra, U. N., Saha, D., … Singhal, R. K. (2023). Plant photosynthesis under abiotic stresses: Damages, adaptive, and signaling mechanisms. *Plant Stress, 10*, 100296.

Christwardana, M., & Hadiyanto, H. (2017). The effects of audible sound for enhancing the growth rate of microalgae *Haematococcus pluvialis* in vegetative stage. *HAYATI Journal of Biosciences, 24*(3), 149-155.

Colbert, B. R. (2020). Trends and developments in international regulation of anthropogenic sound in aquatic habitats. *The Journal of the Acoustical Society of America*, *147*(5), 3100.

El Amin, M. H. (2023). Kajian struktur komunitas dan pertumbuhan kultur campuran mikroalga Situ Babakan menggunakan substrat zeolit dalam bold basal medium dengan variasi konsentrasi logam berat Cu (Master’s thesis). Department of Biology, Universitas Indonesia, West Java, Indonesia.

Guo, M., Noori, R., & Abolfathi, S. (2024). Microplastics in freshwater systems: Dynamic behaviour and transport processes. *Resources, Conservation and Recycling*, *205,* 107578.

Hamdhani, Mangoting, J., & Ghitarina. (2024). Analysis of microplastic content in sediments of two garden ponds located in the Mulawarman University campus. *Jurnal Ilmu Perikanan Tropis Nusantara*, *4*(1), 1–6.

Han, F., Pei, H., Hu, W., Han, L., Zhang, S., & Ma, G. (2016). Effect of high-temperature stress on microalgae at the end of the logarithmic phase for the efficient production of lipid. *Environmental Technology*, *37*(20), 2649-2657. doi: 10.1080/09593330.2016.1158867.

Helfield, B., Chen, X., Watkins, S. C., & Villanueva, F. S. (2016). Biophysical insight into mechanisms of sonoporation. *Proceedings of the National Academy of Sciences*, *113*(36), 9983-9988. doi: 10.1073/pnas.1606915113.

Hendrayanti, D., Prihantini, N. B., Ningsih, F., & Maulana, F. (2023). Next generation sequencing (NGS) for cyanobacterial study in Agung and Sunter Barat Lakes, North Jakarta, Indonesia. *Biodiversitas*, *24*(3), 1117-1124.

Henny, C., & Meutia, A. A. (2014). Urban lakes in megacity Jakarta: Risk and management plan for future sustainability. *Procedia Environmental Sciences*, *20*, 737-746.

Kagan, A. (2025). The decibel: How a tiny unit measures the universe of sound Retrieved from https://www.sonarworks.com/blog/learn/decibel-in-audio.

Kuehne, L. M., Padgham, B. L., & Olden, J. D. (2013). The soundscapes of lakes across an urbanization gradient. *PLoS ONE*, *8*(2), e55661.

Li, Y., Horsman, M., Wang, B., & Wu, N. (2008). Effect of nitrogen sources on cell growth and lipid accumulation of green algae *Neochloris oleoabundans*. *Applied Microbiology and Biotechnology*, *81*(4), 629-636.

Lin, W.-J., Ho, H.-C., Chu, S.-C., & Chou, J.-Y. (2020). Effects of auxin derivatives on phenotypic plasticity and stress tolerance in five species of the green alga *Desmodesmus* (*Chlorophyceae, Chlorophyta*). *PeerJ*, *8*, e8623. doi: 10.7717/peerj.8623.

Maulana, F. (2023). Potensi pemanfaatan konsorsium mikroalga Situ Kenanga, Agathis, dan Rawa Besar Kota Depok sebagai bahan baku biofuel menggunakan modified ultrasound harvesting module (Master's thesis). Department of Biology, Universitas Indonesia, West Java, Indonesia.

Magurran, A. E. (2005). *Measuring biological diversity*. Oxford: Blackwell Publishing.

Odum, E. P. (2004). *Fundamentals of ecology*. Philadelphia: Saunders College Publishing.

Pandey, K. D., Singh, S. K., Shukla, L., Rai, V. K., Singh, R. P., Yadav, P., … Kumar, A. (2023). Mechanistic approaches and factors regulating microalgae mediated heavy metal remediation from the aquatic ecosystem. *Recent Advancements in Wastewater Management: Implications and Biological Solutions*, 285-299. doi: 10.1016/bs.apmp.2022.10.011.

Petriki, O., & Bobori, D. C. (2024). The compositional and functional diversity of a Mediterranean urban lake's fish fauna over the past 120 years. *Applied Sciences*, *14*(14), 6099.

Pikoli, M. R., Sari, A. F., Solihat, N. A., & Permana, A. H. (2019). Characteristics of tropical freshwater microalgae *Micractinium conductrix*, *Monoraphidium* sp. and *Choricystis parasitica*, and their potency as biodiesel feedstock. *Heliyon*, *5*(12), e02922.

Prihantini, N. B., Wardhana, W., Hendrayanti, D., Widyawan, A., Ariyani, Y., & Rianto, R. (2010). Biodiversitas cyanobacteria dari beberapa situ/danau di kawasan Jakarta-Depok-Bogor, Indonesia. *MAKARA of Science Series*, *12*(1), 44-54.

Prihantini, N. B. (2020). Morphological identification, isolation, and culturing of cyanobacteria derived from hot spring of Cisolok and Galunggung Mountain based on enrichment method. *Journal of Physics: Conference Series*, *1442*(1), 012069.

Prihantini, N. B., Rakhmayanti, N., Handayani, S., Sjamsuridzal, W., Wardhana, W., & Nasruddin. (2020). Biomass production of Indonesian indigenous *Leptolyngbya* strain on NPK fertilizer medium and its potential as a source of biofuel. *Evergreen*, *7*(4), 593-601.

Prihantini, N. B., Handayani, S., Rochmanto, N. A. T., Nasruddin, N., & Mahlia, T. M. I. (2024). Enhanced growth and lipid production of Indonesia indigenous filamentous cyanobacteria (*Mastigocladus* HS-46) in a flat photobioreactor using fertilizer medium. *Evergreen*, *11*(3), 1798-1807. doi: 10.5109/7236832.

Prosnier, L. (2024). Zooplankton as a model to study the effects of anthropogenic sounds on aquatic ecosystems. *Science of The Total Environment*, *928*, 172489.

Rajan, A., & Gaurav, K. (2023). Production of biohydrogen by *Scenedesmus obliquus* and yield comparison with various pre-treatment methods. *Journal of Advanced Chemical Sciences*, *9*(1), 788-790

Ren, H.-Y., Xiao, R.-N., Kong, F., Zhao, L., Xing, D., Ma, J., … Liu, B.-F. (2019). Enhanced biomass and lipid accumulation of mixotrophic microalgae by using low-strength ultrasonic stimulation. *Bioresource Technology*, *272*, 606-610.

Santoso, Y. A., Tambunan, R. M. N., Soekirno, S., Nasruddin, N., & Prihantini, N. B. (2020a). Sound wave exposure as a strategy for improving the tubular photobioreactor for cultivating *Synechococcus* HS-9 as biofuel feedstock under different photoperiods. *International Journal of Technology*, *11*(7), 1406-1414.

Santoso, Y. A., Tambunan, R. M. N., Soekirno, S., Nasruddin., & Prihantini, N. B. (2020b). Cultivation of *Synechococcus* HS-9 (cyanobacteria) isolated from Rawa Danau Banten hot spring using audible sound (music) as a strategy for improving photobioreactor. *International Conference on Trends in Material Science and Inventive Materials: ICTMIM 2020*.

Stiling, P. (2001). *Ecology: Theories and applications*. New Jersey: Prentice Hall.

Shi, T.-Q., Wang, L.-R., Zhang, Z.-X., Sun, X.-M., & Huang, H. (2020). Stresses as first-line tools for enhancing lipid and carotenoid production in microalgae. *Frontiers in Bioengineering and Biotechnology*, *8*, 610.

Tambunan, R. M. N., Santoso, Y. A., Soekirno, S., Nasruddin., & Prihantini, N. B. (2020). Cultivation of *Chlorella* DPK-01 using audible sound (music) as a potential strategy for improving photobioreactor system. *International Conference on Trends in Material Science and Inventive Materials: ICTMIM 2020*.

Tambunan, R. M. N., Santoso, Y. A., Soekirno, S., Nasruddin., & Prihantini, N. B. (2021). Difference in time of audible sound exposure to *Chlorella* DPK-01 in tubular photobioreactors: A strategy to improve photobioreactor system. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *81*(2), 82-88.

Tambunan, R. M. N., & Prihantini, N. B. (2023). Biomass production of Subang isolated *Scenedesmus* in tube-shaped photobioreactor with the exposure of audible sound (music): Photobioreactor improvement strategy. *Jurnal Penelitian Pendidikan IPA*, *9*(3), 1412-1417.

Tambunan, R. M. N., Soekirno, S., Nasruddin, N., & Prihantini, N. B. (2024). Effect of audible sound exposure on the growth and lipid content of *Chlorella* DPK-01 cultivated in photobioreactor system using different growth media. *Evergreen*, *11*(1), 106-115.

Tan, C., Greulich, S., Medina, V., Zheng, X., Canu, P., Fritsch, A., ... Wantzen, K. M. (2024). Still exotic? comparison of macroinvertebrates associated with *Elodea nuttallii* and native macrophytes in urban artificial lakes. *Hydrobiologia*, *851*(18), 4461-4475.

Teurlincx, S., Kuiper, J. J., Hoevenaar, E. C., Lurling, M., Brederveld, R. J., Veraart, A. J., … de Senerpont Domis, L. N. (2019). Towards restoring urban waters: Understanding the main pressures. *Current Opinion in Environmental Sustainability*, *36*, 49-58.

Valenzisi, B., Parsons, M., Huggett, M., Raoult, V., & Gaston, T. (2024). Urbanisation and boating are the main contributors to underwater soundscapes in three temperate estuaries. *Marine Pollution Bulletin*, *206*, 116792.

Wang, Z., Xu, Y., Yang, J., Li, Y., Sun, Y., Zhang, L., & Yang, Z. (2022). Adverse role of colonial morphology and favorable function of microcystins for *Microcystis* to compete with *Scenedesmus*. *Harmful Algae*, *117*, 102293.

Wei, Q., Yao, J., Chen, R., Yang, S., Tang, Y., & Ma, X. (2022). Low-frequency ultrasound and nitrogen limitation induced enhancement in biomass production and lipid accumulation of *Tetradesmus obliquus* FACHB-12. *Bioresource Technology*, *358*, 127387.

Yan, Z., Liu, Z., Jia, Z., Song, C., Cao, X., & Zhou, Y. (2023). Metabolites of extracellular organic matter from *Microcystis* and *Dolichospermum* drive distinct modes of carbon, nitrogen, and phosphorus recycling. *Science of The Total Environment*, *865*, 161124.

Yanti, N. W. K. E., Rochmanto, A. T., Handayani, S., Nasruddin., & Prihantini, N. B. (2021). Optimization of NPK medium with the addition of mung bean sprout extract for biomass and lipid production of *Stanieria* HS-48 as a potential biofuel. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *82*(1), 77-84.