

DIFFERENCES IN PLANKTON COMMUNITY STRUCTURE BASED ON ABUNDANCE AND BIOMASS IN A TROPICAL RESERVOIR

Syahnan Aly Lubis^{*1}, Riska Aprisanti¹, and Zakiah²

¹ Department of Aquatic Resource Management, Faculty of Aquatic and Marine Sciences, University of Riau, Pekanbaru, Indonesia

² Department of Fisheries, Faculty of Agriculture, University of Palangka Raya, Palangkaraya, Indonesia

Email: syahnan.alys@lecturer.unri.ac.id

ABSTRACT

Plankton are important bioindicators for assessing the ecological condition of water bodies. However, an abundance based approach does not always reflect energy distribution within an ecosystem because small organisms can dominate numerically without contributing comparable biomass. This situation can cause ecological decoupling, a discrepancy in ecological interpretation between abundance-based and biomass-based indicators. This study aims to analyze and compare plankton community structure based on abundance and biomass and to evaluate the presence of ecological decoupling in the Koto Panjang Reservoir as a representative of a tropical reservoir influenced by hydrological dynamics and anthropogenic pressures. The study was conducted from May 2025 to April 2026 at six stations representing the riverine, transitional, and lacustrine zones. Plankton samples were analyzed using the Sedgwick–Rafter Counting Cell method, while biomass was estimated using the biovolume approach. The analysis included Bray–Curtis cluster analysis, ecological indices, Pearson correlation, linear regression, and Bland–Altman analysis. The results revealed three distinct spatial zones (riverine, transitional, and lacustrine), with plankton communities dominated by *Staurostrum* spp., members of the Desmidiaceae family. Phytoplankton abundance ranged from 531,000 to 1,297,000 cells L⁻¹, while phytoplankton biomass ranged from 0.19 to 0.85 mg L⁻¹. Abundance-based indices showed higher Shannon diversity values (2.74–2.97) compared to biomass-based indices (0.54–0.66). The relationship between the two approaches was relatively weak ($r = 0.41\text{--}0.48$; $R^2 = 0.17\text{--}0.23$) indicating differences in how community structure is represented. Pearson correlation analysis, linear regression, and Bland–Altman plots revealed a weak relationship and low agreement between the two approaches, confirming ecological decoupling. These findings suggest that integrating abundance- and biomass-based indicators is necessary to make assessments of the ecological condition of tropical reservoirs more comprehensive and representative of community structure and energy distribution within the ecosystem.

Keywords: Biomass; Decoupling; Abundance; Plankton; Tropical Reservoir; Spatial Zoning

INTRODUCTION

In aquatic ecology, plankton has long been used as a primary bioindicator for assessing trophic status and ecosystem health. Abundance-based ecological indices are widely used because they are sensitive to changes in individual numbers and relatively easy to measure. These indices help explain plankton population dynamics and their impact on the entire aquatic ecosystem (Sahoo *et al.*, 2024). However, abundance-based approaches have limitations because they tend to assign equal weight to all individuals without considering body size or their contribution to energy flow within the ecosystem. Consequently, small-sized organisms can dominate abundance values even though their biomass and ecological contributions are relatively low. In contrast, plankton biomass reflects the accumulation of organic matter, community size structure, and energy distribution and is therefore considered more representative of ecosystem function. Nevertheless, the relationship between abundance and biomass is not always linear and is often influenced by community structure, organism size, and dynamic environmental conditions (Andersen & Visser, 2023; García-Comas *et al.*, 2016; Gjoni *et al.*, 2023).

Differences between abundance and biomass can give rise to ecological decoupling, a condition in which two metrics used to describe a biological community yield different ecological interpretations because each represents a distinct ecological aspect. In plankton communities, decoupling can

occur when small-sized species dominate numerically but contribute little biomass. In contrast, larger species have lower abundance yet dominate biomass distribution and ecosystem energy flow (Sugie & Suzuki, 2015). Several studies indicate that the relationship between plankton abundance and biomass is not always proportional and is influenced by variations in body size, trophic dynamics, community composition, and environmental heterogeneity (García-Comas *et al.*, 2016). Furthermore, changes in the size structure of plankton communities can alter energy transfer efficiency and ecosystem productivity without necessarily being accompanied by changes in the number of individuals (González-García *et al.*, 2023; Marrec, 2024). These conditions indicate that approaches based on abundance and biomass do not always provide consistent ecological signals; therefore, evaluating ecological decoupling is crucial for improving the accuracy of ecosystem condition interpretations.

Ecological decoupling is expected to become increasingly complex in tropical reservoir ecosystems with high hydrological dynamics because of interactions between climate variability and dam operations. Fluctuations in water level, changes in water residence time, nutrient distribution, and water column stratification patterns can influence the size structure of plankton communities and energy transfer efficiency within the ecosystem. Consequently, changes in plankton abundance are not always accompanied by changes in biomass in the same pattern, potentially reinforcing the decoupling between these

two approaches (Choonamchai *et al.*, 2025; Cunha *et al.*, 2021). Thus, tropical reservoirs represent an ideal system for evaluating the extent to which abundance- and biomass-based approaches provide complementary or divergent ecological information.

The Koto Panjang Reservoir in Riau Province is a tropical reservoir system under high hydrological stress. Recent data indicate a 22-cm drop in water level over a short period due to an imbalance between inflow and outflow. Additionally, a significant decrease in inflow has been reported, affecting the stability of the reservoir system, although it remains within safe operational limits. These conditions reflect the reservoir's high sensitivity to hydrological variability influenced by climatic factors and dam management, which may impact plankton community dynamics.

Although various studies have been conducted at the Koto Panjang Reservoir to evaluate the water body's ecological conditions, most have focused on trophic status, limnological characteristics, water quality, and the distribution of phytoplankton and nutrients. The trophic status in the lacustrine zone has been evaluated using various limnological indicators to describe the water body's fertility level. At the same time, vertical profiles of dissolved oxygen, nitrate, phosphate, and BODs have been examined to explain water quality dynamics in the lacustrine and transitional zones of the reservoir (Siagian & Simarmata, 2018; Silaen *et al.*, 2017; Wehalo *et al.*, 2017). In addition, variations in phytoplankton abundance around floating net cage areas, as well as the distribution of phytoplankton and chlorophyll-a, have been analyzed as indicators of changes in ecological conditions and productivity levels in the reservoir *et al.*, 2024).

These studies are still dominated by approaches based on phytoplankton abundance, chlorophyll-a concentration, and limnological parameters; consequently, plankton biomass has not yet been utilized as a basis for a comprehensive evaluation of community structure. Furthermore, a direct comparison between abundance-based and biomass-based ecological indices to identify potential ecological decoupling has never been conducted at the Koto Panjang Reservoir. To date, no study has evaluated the level of agreement between these two approaches using statistical methods such as Bland–Altman analysis; consequently, it remains unknown whether abundance- and biomass-based indices yield consistent ecological interpretations or, conversely, provide differing information about ecosystem conditions. Therefore, this study was conducted to fill this knowledge gap by quantitatively evaluating the relationship and degree of agreement between abundance- and biomass-based indices in the plankton community at Koto Panjang Reservoir.

RESEARCH METHODS

Study Period and Location

This study was conducted from May 2025 to April 2026 at Koto Panjang Reservoir, Riau Province, Indonesia. A total of six observation stations were established to represent the reservoir's longitudinal ecological gradient, encompassing the riverine, transitional, and lacustrine zones. Sampling was conducted quarterly (every three months), resulting in four sampling campaigns during the study period. During each

sampling period, water collected from the three sub-stations at the same station was homogenized into a single composite sample to produce a sample representative of that station's conditions. This composite approach reduced the influence of small-scale spatial variation while yielding more representative estimates of water quality characteristics and plankton communities at the station level. Thus, although 72 field samples (6 stations × 3 sub-stations × 4 sampling periods) were collected during the study, statistical analysis used 24 composite samples (6 stations × 4 sampling periods). Figure 1 shows the study locations, and Table 1 presents the geographic coordinates and characteristics of each station.

Table 1. Study Locations and Coordinates

Location	Coordinate
Station 1	0°20'31.80"N; 100°39'18.50"E
Station 2	0°21'02.58"N; 100°43'24.24"E
Station 3	0°18'48.50"N; 100°46'35.69"E
Station 4	0°17'11.22"N; 100°43'29.44"E
Station 5	0°16'49.31"N; 100°49'37.04"E
Station 6	0°17'11.30"N; 100°52'36.77"E

Spatial Zones of the Reservoir Waters

The spatial zoning patterns of the reservoir were identified using hierarchical cluster analysis based on average total plankton abundance data at each observation station. The values used were the averages from four quarterly sampling periods during the study (May 2025–April 2026), so that each station was represented by a single average abundance value that reflected general ecological conditions and minimized the influence of short-term seasonal fluctuations. This approach was chosen because the objective of the cluster analysis was to identify relatively stable spatial zonation at the reservoir scale, rather than to evaluate the temporal dynamics of the plankton community.

Before the analysis, the abundance data were transformed using the $\log(x+1)$ function to minimize the influence of extreme values, reduce distribution skewness, and improve data homogeneity so the clustering results could more accurately represent patterns of similarity among stations (*et al.*, 2022). Next, we calculated the similarity matrix among stations using the Bray–Curtis index, which is commonly used in biological community analysis because it is sensitive to differences in species composition and abundance (Oksanen *et al.*, 2024).

Cluster analysis was performed using an agglomerative method with Ward's linkage algorithm. The clustering results were visualized as a dendrogram to identify groups of stations with similar plankton community characteristics. The optimal number of clusters was determined based on the *similarity level* and ecological interpretation, resulting in three main groups representing the riverine, transitional, and lacustrine zones.

Biomass data were not used as the basis for zonation cluster formation because this analysis aimed to identify spatial gradients in the ecosystem based on the general structure of the plankton community. Abundance was selected as the primary variable because it is more sensitive in describing changes in community composition along environmental gradients and is more commonly used in community similarity analysis. Conversely, biomass was used in the subsequent analysis stage to evaluate ecological decoupling between the numerical and

functional structures of the plankton communities. Thus, the spatial zoning obtained through cluster analysis served as the

spatial framework used to interpret differences in abundance and biomass patterns across zones.

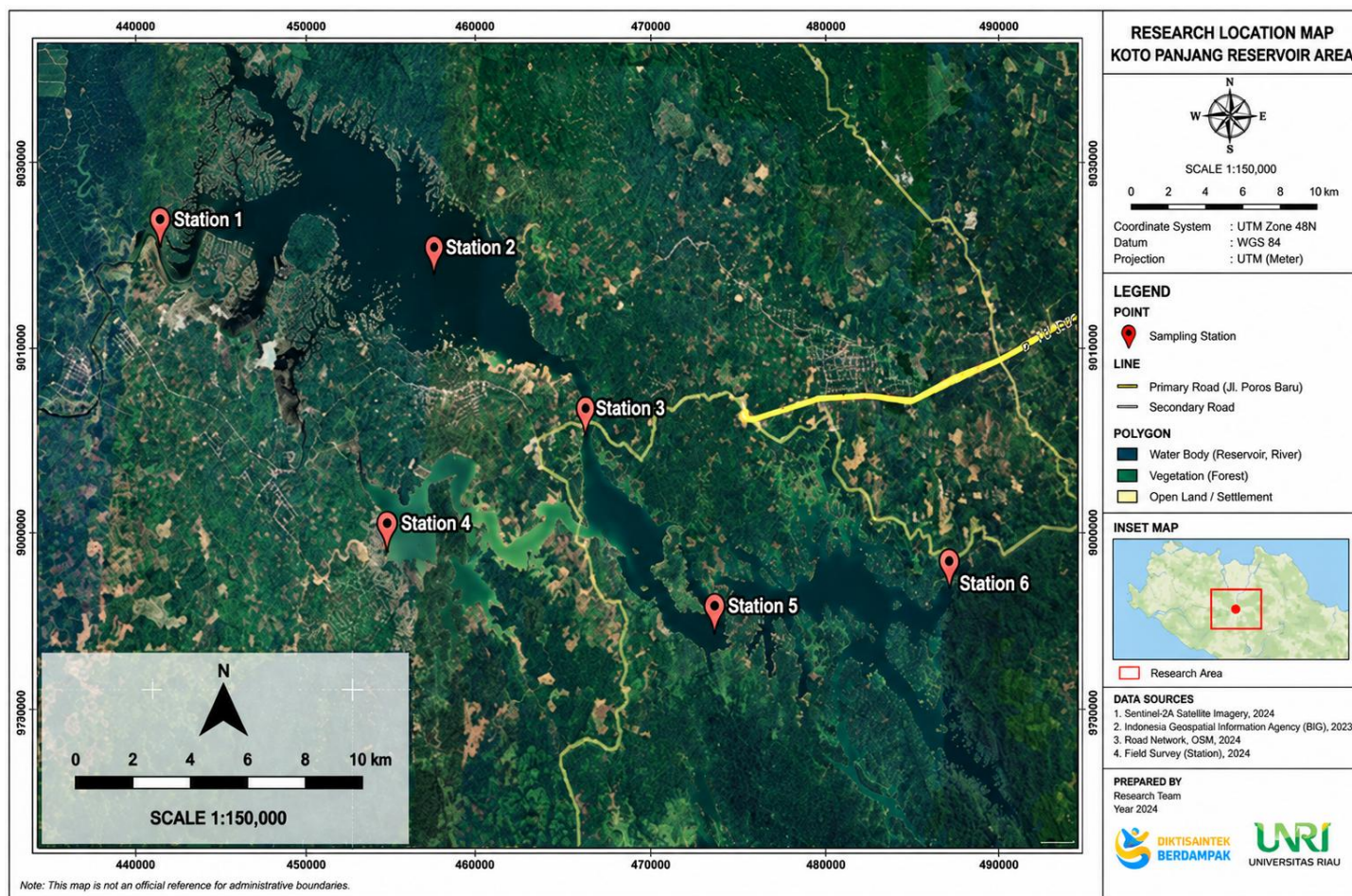


Figure 1. Research Location in the Koto Panjang Reservoir Area

Plankton Sampling and Preparation

Phytoplankton and zooplankton sampling was conducted in a standardized manner, following classical limnological methods and the international standard. At each sub-station, approximately 100 L of surface water was collected via direct grab sampling using a clean polyethylene bucket, then filtered in situ using a 20 µm plankton net to obtain a plankton concentrate of approximately 100 mL. Filtration was performed in stages to prevent mesh clogging from high levels of suspended particles and maintain filtration efficiency.

The phytoplankton concentrate was preserved in 1% Lugol's solution to maintain cellular morphology while halting biological activity. Lugol's solution also enhances cellular contrast, facilitating microscopic identification (Sherr & Sherr, 2018). The samples were then stored in dark bottles to prevent light-induced degradation.

Zooplankton samples were collected separately by filtering 100 L of water through a plankton net with a mesh size of 20 µm, then concentrating the filtrate to approximately 100 mL. Using the same mesh size for both phytoplankton and zooplankton was intended to retain the small-sized zooplankton fraction. Zooplankton samples were preserved using 70% ethanol to maintain body morphology, thereby enabling more accurate taxonomic identification (Association, 2017; Dodson & Frey, 2001).

Before analysis, the samples were gently homogenized

to ensure an even distribution of organisms, given that plankton tends to settle during storage. This homogenization step is crucial to ensure that the subsamples taken truly represent the entire sample.

Data Analysis

Plankton Abundance Analysis

Plankton counts were performed using the Sedgwick–Rafter Counting Cell (SRC) method with a counting chamber volume of 1 mL. This method was chosen because it allows direct quantitative estimation based on the measured sample volume (Association, 2017). Plankton abundance was calculated by considering the number of individuals observed, the volume of the concentrate, the observed volume, and the volume of filtered water. Mathematically, abundance is expressed as:

$$N = n \times \frac{V_{\text{concentrat}}}{V_{\text{Observed}}} \times \frac{1}{V_{\text{filtered}}} \dots \dots \dots (1)$$

In this equation, N is the plankton abundance (ind/L), n is the number of individuals counted in the Sedgwick–Rafter Counting Cell (SRC), $V_{\text{concentrat}}$ is the final sample volume (100 mL), V_{Observed} is the observed sample volume (1 mL), and V_{filtered} is the volume of filtered water (100 L).

This equation is used because it integrates all stages of sample concentration, thereby yielding standardized abundance

values that can be compared across locations and observation times (Wetzel, 2001).

Plankton Biomass Estimation

Plankton biomass is calculated using the biovolume approach, which converts the morphological size of organisms into a mass estimate (Hillebrand *et al.*, 1999; Sun & Liu, 2003). Mathematically, biomass is calculated as.

$$B = N \times V \times \rho \times 10^{-12} \quad (2)$$

In this equation, B represents plankton biomass (mg/L), N represents plankton abundance (ind/L), V represents the average cell volume (μm^3), and ρ represents the density of the organisms, assumed to be $\pm 1 \text{ g/cm}^3$.

Calculation of Ecological Indices

Plankton ecological indices are calculated using two approaches—abundance-based and biomass-based—to test for potential differences in the interpretation of ecosystem conditions. The Shannon-Wiener diversity index is calculated using the equation (Spellerberg, 2008).

$$H' = -\sum p_i \ln p_i \quad (3)$$

H' is the Shannon-Wiener diversity index, p_i is the proportion of individuals or biomass of species i relative to the total number of individuals or biomass, $\ln$ is the natural logarithm, and i denotes species i .

This index was chosen because it captures community complexity by considering both the number of species and their relative proportions (Shannon & Weaver, 1949). The Simpson dominance index was calculated using (Wulandari *et al.*, 2023).

$$D = -\sum p_i^2 \quad (4)$$

D is the Simpson dominance index, and p_i is the proportion of individuals or biomass of the i -th species relative to the total number of individuals or biomass. Meanwhile, the evenness index is calculated using.

$$E = \frac{H'}{\ln S} \quad (5)$$

In this equation, E is the evenness index, H' is the Shannon-Wiener diversity index, S is the number of species found, and $\ln$ is the natural logarithm.

Analysis of Decoupling Between Abundance and Biomass

The presence of *ecological decoupling* between abundance-based and biomass-based approaches was evaluated through a series of statistical analyses. The linear relationship between the two approaches was analyzed using Pearson's correlation, while the strength and direction of the relationship were evaluated through linear regression analysis (Pearson, 1895).

$$y = a + bx \quad (6)$$

However, since a strong correlation does not always indicate agreement, Bland-Altman analysis was used to evaluate

differences between methods (Bland & Altman, 1986).

$$d = X_1 - X_2 \quad (7)$$

$$d \pm 1.96 SD \quad (8)$$

This approach allows for the identification of systematic bias as well as the limits of agreement between two measurement methods. To test for the decoupling phenomenon between abundance-based and biomass-based approaches, a stepwise statistical analysis was conducted.

1. Pearson's correlation to test for a linear relationship
2. Linear regression to evaluate the strength of the relationship
3. Bland-Altman analysis to evaluate agreement between methods

RESULTS AND DISCUSSION

Spatial Zoning

The cluster analysis results showed clear groupings of stations based on similarities in plankton abundance (Figure 2). The dendrogram showed that the stations could be divided into three main groups. The first cluster consists of Station 1 and Station 2, representing the riverine zone. The second cluster consists of Station 3 and Station 4, representing the transition zone, while the third cluster consists of Station 5 and Station 6, representing the lacustrine zone with the highest abundance.

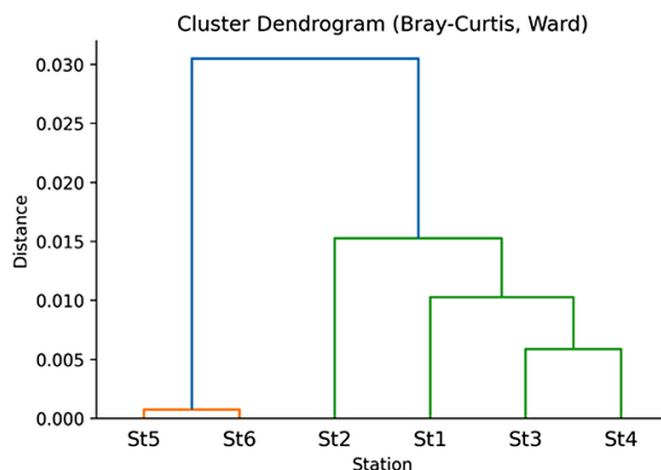


Figure 2. Spatial zoning

The ANOSIM test yielded an R value of 0.463 with $p = 0.082$, indicating that differences in plankton community structure among zones are not yet statistically significant at the 5% level. Nevertheless, the R value—which falls into the moderate category—suggests a tendency toward separation of plankton communities across zones, although variation within each group remains relatively high. The PERMANOVA analysis yielded a Pseudo- F value of 10.27, indicating that multivariate variation between groups is relatively greater than variation within groups. Differences in interpretation between ANOSIM and PERMANOVA may arise because the two methods have different sensitivities to multivariate data structures. ANOSIM is based on the ranks of the similarity matrix and is therefore more sensitive to the degree of separation between groups. In contrast, PERMANOVA evaluates

differences in *centroid* positions between groups based on variance partitioning and can be influenced by heterogeneity in dispersion within groups. Therefore, the results of both analyses in this study are viewed as complementary information for interpreting the spatial zoning patterns of the reservoir, rather than as conflicting results.

Ecologically, the clustering patterns generated by the cluster analysis still indicate a longitudinal gradient from the riverine zone to the lacustrine zone. This gradient is common in reservoir ecosystems and is influenced by changes in hydrological conditions, water residence time, nutrient availability, and the morphological characteristics of the water body along the upstream–downstream gradient (*et al.*, 2026). Thus, although differences in community structure between zones have not been proven to be statistically significant in multivariate analysis, the clustering patterns that emerge still indicate a trend of change in plankton community composition along the reservoir's spatial gradient.

Differences in patterns between phytoplankton and zooplankton were also clearly evident in this study. Phytoplankton exhibited greater spatial variation compared to zooplankton, which was relatively more homogeneous across stations. Differences in ecological function may explain this: phytoplankton, as primary producers, respond strongly to changes in nutrients and light, whereas zooplankton are more influenced by trophic interactions such as predation and food availability (Kämpf *et al.*, 2023). These variations indicate a combination of bottom-up (nutrient) and top-down (predation) controls in shaping plankton community structure.

In addition to natural factors, anthropogenic activities such as fish farming using floating net pens (FNP) also significantly increase nutrient loads in aquatic environments. Feed waste and fish excreta from FNCs increase nitrogen and phosphorus concentrations, which can significantly stimulate phytoplankton growth (Sunardi & Oktavia, 2023). In tropical reservoirs, this nutrient accumulation tends to be higher in the lacustrine zone due to longer water residence times, thereby reinforcing the spatial gradient of plankton abundance.

The interaction between spatial gradients, nutrient enrichment resulting from floating net cage (FNC) activities, and climate change pressures produces complex plankton distribution patterns in the Koto Panjang Reservoir. This indicates that plankton dynamics in tropical reservoirs are controlled not only by natural physical factors but also by anthropogenic pressures and global environmental changes that interact to shape community structure and ecosystem productivity.

Plankton Abundance and Biomass

Plankton abundance varied distinctly across the six observation stations in the reservoir. Phytoplankton abundance ranged from 531,000 to 1,297,000 cells/L, while zooplankton abundance ranged from 15,000 to 26,000 individuals (Figure 3). Plankton biomass showed a different spatial pattern than abundance. Phytoplankton biomass ranged from 0.19 to 0.85 mg/L, while zooplankton biomass ranged from 4.14 to 6.28 mg/L. Phytoplankton biomass showed an increasing trend toward the lacustrine zone (Figure 4). Comparing plankton abundance and biomass reveals differences in distribution patterns among stations. In general, stations with high abundance do not always exhibit high biomass (Figure 5).

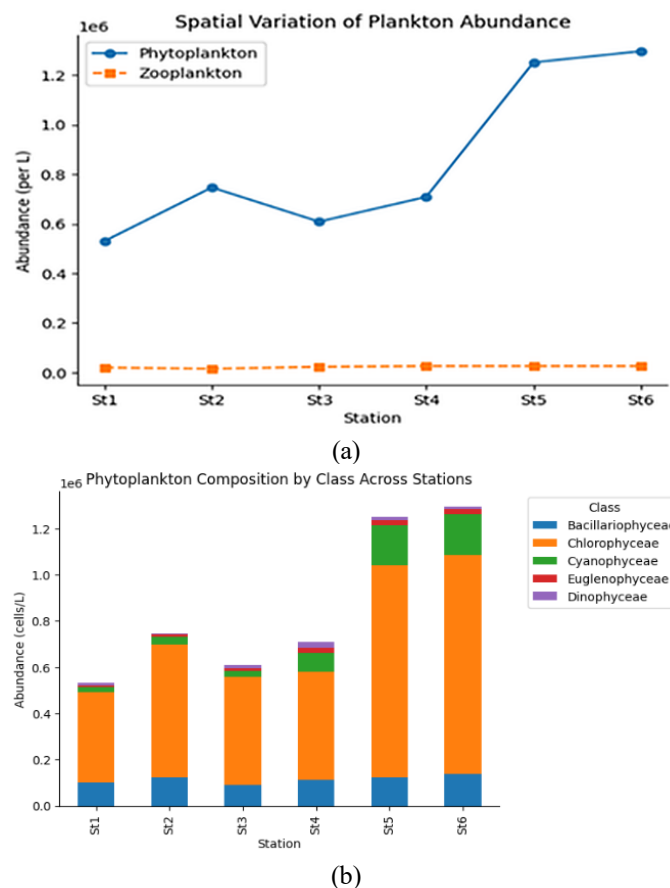


Figure 3. (a) Plankton Abundance and (b) Plankton Composition

Zooplankton biomass was consistently higher than phytoplankton biomass at all observation stations (Figure 5), indicating the formation of an inverted biomass pyramid. Although this pattern appears to contradict the classical concept of a trophic pyramid, it has been widely reported in aquatic ecosystems particularly lakes and reservoirs characterized by high primary productivity and extremely rapid phytoplankton biomass turnover. Under such conditions, the phytoplankton biomass measured at a given time may remain low because newly produced biomass is immediately consumed by herbivores. In contrast, zooplankton can maintain a larger standing biomass because of longer generation times and slower biomass turnover rates. Thus, consumer biomass can exceed primary producer biomass without contradicting the principle of energy flow, because energy transfer within an ecosystem is determined by the rate of production, not by the magnitude of standing biomass.

The inverted biomass pyramid phenomenon in the Koto Panjang Reservoir likely also reflects efficient trophic energy transfer supported by continuous phytoplankton production under nutrient-rich tropical aquatic conditions. Nutrient input from floating net cage aquaculture and the watershed allows phytoplankton to continuously regenerate even though biomass is temporarily relatively low due to grazing pressure from zooplankton. Therefore, the observed biomass structure better reflects a dynamic balance between primary production and consumption rather than indicating low primary productivity.

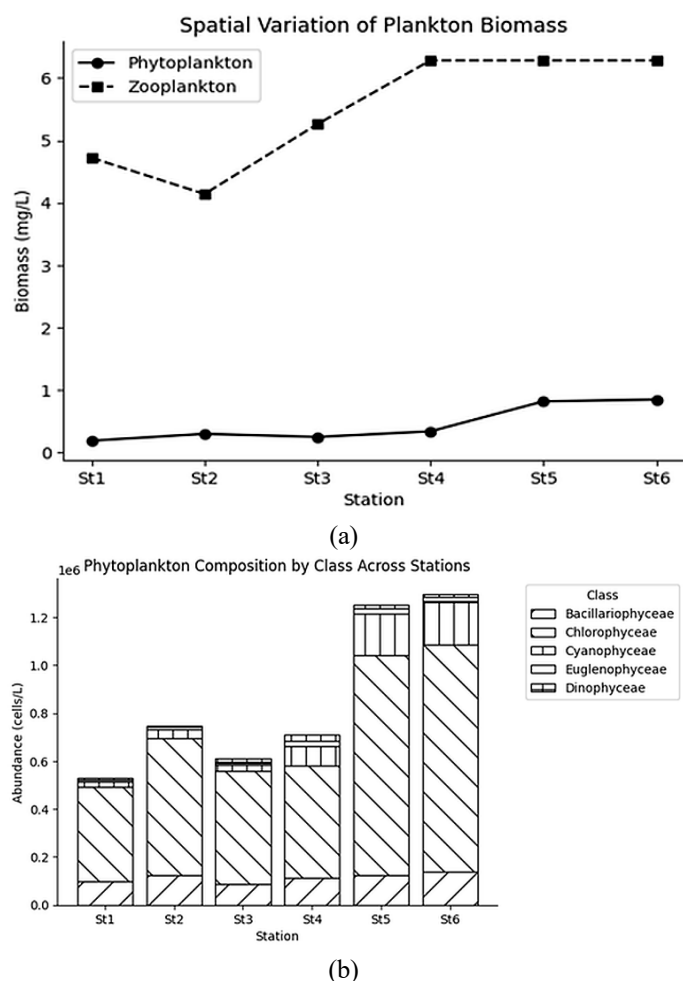


Figure 4. (a) Plankton Biomass and (b) Biomass Composition

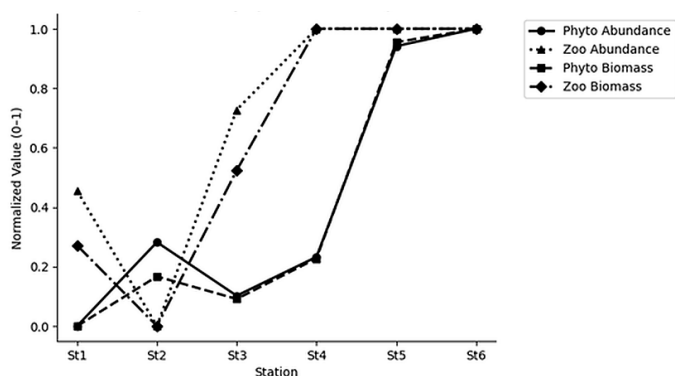


Figure 5. Comparison of Phytoplankton and Zooplankton Abundance and Biomass at Each Station (Normalized Values)

Phytoplankton abundance increased consistently from Station 1 to Station 6, with the highest values at Stations 5 and 6. However, biomass did not follow this pattern. Although phytoplankton biomass showed an increasing trend from the riverine zone toward the lacustrine zone, this pattern did not fully correspond to changes in abundance. At Station 2, the increase in abundance compared to Station 1 was not accompanied by an increase in biomass. Conversely, biomass increased significantly at Station 3 and reached its maximum value at Station 4, while abundance did not reach its maximum

until Stations 5 and 6. This difference in patterns indicates that changes in the number of individuals do not always occur proportionally to changes in biomass, suggesting that size structure and species composition influence the distribution of community biomass.

These differences are primarily influenced by the size and morphological characteristics of the species comprising the community. Species with large cell sizes contribute more to biomass even though they have fewer individuals, whereas small species may dominate numerically but contribute little to biomass. A similar pattern is also observed in zooplankton, where biomass varies more homogeneously than abundance, indicating that energy distribution does not depend entirely on the number of individuals.

The differences between the abundance-based and biomass-based approaches in this study indicate that the two approaches provide different representations of plankton community structure. Based on the abundance-based approach, the Shannon diversity index (H') ranged from 2.4 to 3.2 (mean 2.85 ± 0.10), the Simpson index ($1-D$) ranged from 0.88 to 0.98 (mean 0.925 ± 0.009), and the evenness index (E) ranged from 0.80 to 1.00 (mean 0.915 ± 0.026). In contrast, the biomass-based approach yielded significantly lower Shannon values, ranging from 0.54 to 0.66 (mean 0.59 ± 0.05), Simpson's index of 0.24–0.34 (mean 0.283 ± 0.038), and an evenness index of 0.23–0.30 (mean 0.263 ± 0.026). These values indicate that the abundance-based approach describes a community with high levels of diversity and evenness, whereas the biomass-based approach indicates stronger dominance by a small number of taxa that contribute a relatively large share of the biomass. Thus, the abundance-based approach better represents the distribution of individual numbers, whereas the biomass-based approach better reflects the distribution of energy and the functional contributions of organisms within the ecosystem (Smith, 2025).

Ecologically, this difference can be explained by variations in cell size and plankton life strategies. Small phytoplankton species generally have high reproduction rates, allowing them to dominate communities numerically and produce high values of diversity and evenness. Conversely, larger species, such as some members of the Desmidiaceae (*Staurastrum* spp.) or colonies of Chlorophyceae, contribute significantly more biomass despite their relatively low abundance, resulting in lower biomass-based index values due to the increased dominance of certain taxa (Iatskiu *et al.*, 2018).

Biomass-based approaches are also more sensitive to changes in community size structure, which is an important aspect of plankton ecology. Size structure plays a role in determining the efficiency of energy transfer within food webs, where larger organisms tend to play a more significant role in the flow of energy toward higher trophic levels (González-García *et al.*, 2023). Therefore, biomass is often considered a more representative indicator of ecosystem function than abundance alone.

Furthermore, the difference between these two approaches is also related to ecosystem control mechanisms, namely bottom-up and top-down control. Plankton abundance is more influenced by nutrient availability (bottom-up control), whereas biomass better reflects the complex interactions among growth, predation, and energy-use efficiency (Morozov *et al.*, 2019). This explains why abundance and biomass patterns do

not always align in this study.

In tropical reservoirs such as Koto Panjang, this distinction becomes even more significant because of dynamic environmental conditions and high anthropogenic pressures, such as nutrient enrichment from floating cage aquaculture activities. These conditions can promote the dominance of certain species that are highly efficient at utilizing nutrients, resulting in more pronounced differences between abundance and biomass distributions. Overall, these results indicate that abundance- and biomass-based approaches offer distinct yet complementary perspectives for understanding plankton community structure. Relying on a single approach risks producing an incomplete interpretation, particularly in complex tropical aquatic systems influenced by various environmental pressures.

Decoupling in Ecological Indices (Abundance and Biomass)

A comparative analysis of abundance- and biomass-based ecological indices revealed a discrepancy (ecological decoupling) in describing the plankton community structure in

the Koto Panjang Reservoir. In general, abundance-based indices indicate high and relatively stable diversity values across all stations, whereas biomass-based indices yield lower values with greater spatial variation (Figure 6). This discrepancy suggests that the two approaches capture different ecological dimensions and do not provide fully consistent information about plankton community structure.

The relationship between abundance-based and biomass-based indices shows a positive but relatively weak to moderate correlation. The Shannon index has a correlation coefficient of $r = 0.48$ with $R^2 = 0.23$ ($p = 0.29$), the Simpson index shows $r = 0.44$ with $R^2 = 0.20$ ($p = 0.34$), while the Evenness index has $r = 0.41$ with $R^2 = 0.17$ ($p = 0.39$) (Figure 6). The low R^2 values indicate that only 17–23% of the variation in biomass-based indices can be explained by abundance-based indices. Thus, an increase in the number of plankton individuals is not always accompanied by an increase in community biomass, meaning the two approaches do not exhibit a strong linear relationship.

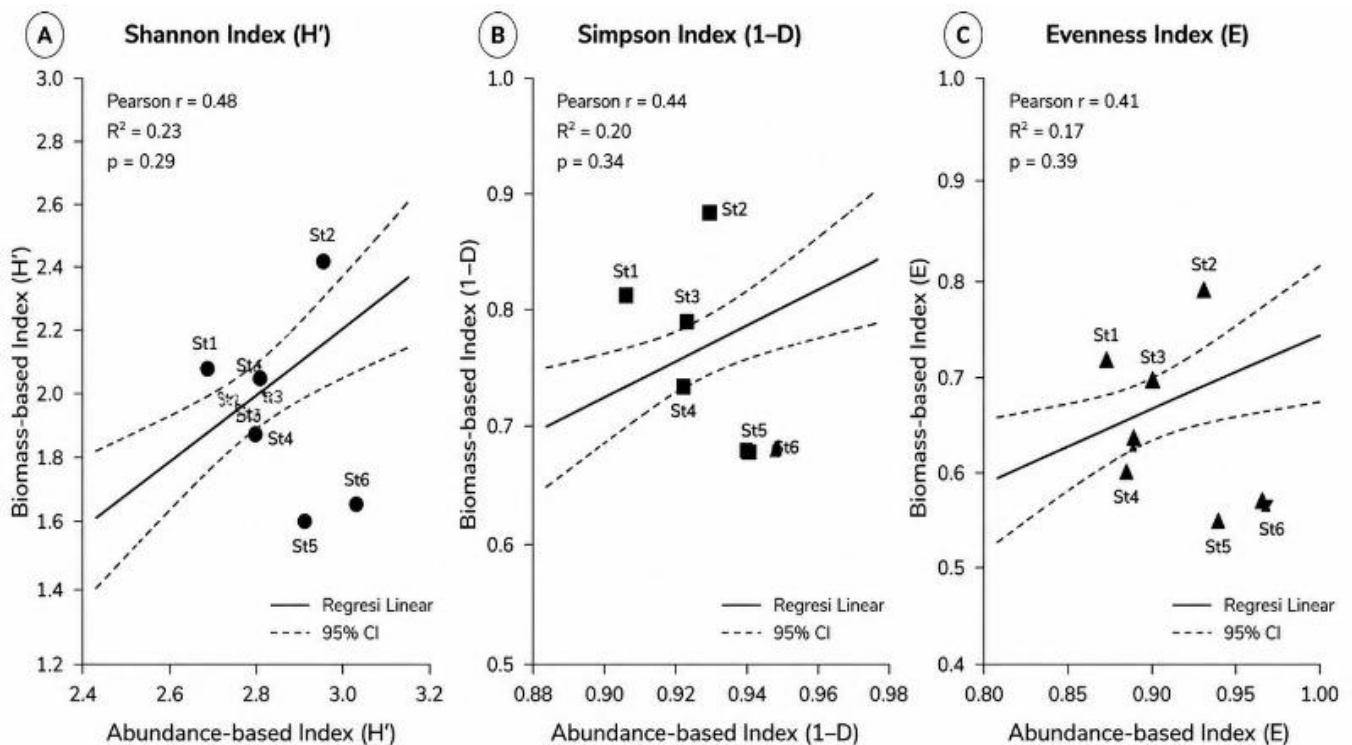


Figure 6. Relationship Between Abundance- and Biomass-Based Indices

The Bland–Altman analysis further reinforces ecological decoupling between the two approaches. The Shannon index showed a mean bias of -2.255 with 95% Limits of Agreement (LoA) ranging from -2.490 to -2.020 . A similar pattern was also observed for the Simpson index, with a mean bias of -0.642 (95% LoA = -0.725 to -0.558), and for the Evenness index, with a mean bias of -0.652 (95% LoA = -0.740 to -0.564). All mean biases were negative, indicating that the biomass-based approach consistently produced lower index values than the abundance-based approach. Furthermore, the relatively narrow range of the Limits of Agreement indicates that these differences are systematic across all observation stations and not due to random variation. Thus, the two approaches are not interchangeable when evaluating plankton community structure.

Ecological decoupling is primarily driven by differences in body size and morphology among species in the community. Species with large cell sizes, such as *Staurastrum* spp. and *Sphaerocystis* spp., contribute significantly more biomass despite their relatively low abundance. Conversely, small species can dominate the community numerically without contributing comparably to biomass. Therefore, the abundance-based approach better reflects the community's numerical structure. In contrast, the biomass-based approach better represents the functional structure, energy distribution, and ecological contributions of organisms within the ecosystem.

This finding is one of the study's key innovations: the applying Bland–Altman analysis as a quantitative approach to evaluate ecological decoupling between abundance- and biomass-based ecological indices in plankton communities in

tropical reservoirs. Unlike correlation and regression analyses, which evaluate relationships between variables, the Bland–Altman plot assesses agreement between approaches, enabling identification of systematic biases that correlation analysis alone cannot detect. These results indicate that abundance- and biomass-based indices capture different yet complementary ecological aspects. Therefore, using both approaches simultaneously provides a more comprehensive representation of plankton community structure and ecosystem conditions than either indicator alone.

Implications for Ecology

The finding of ecological decoupling between abundance- and biomass-based approaches has important implications for interpreting plankton community structure and managing reservoir ecosystems. The differences between these two approaches indicate that using a single indicator, particularly one based on abundance, can yield an incomplete interpretation of the ecological conditions of the water body. In this study, the plankton community was still dominated by the Desmidiaceae and, particularly *Staurastrum* sp., which contributed a relatively large biomass despite not always being numerically dominant. *Staurastrum* is generally associated with waters of low to moderate fertility (oligotrophic–mesotrophic), as most of its species thrive in waters with relatively good water quality and moderate nutrient concentrations.

However, the conditions in the Koto Panjang Reservoir cannot be fully classified as oligotrophic. Previous studies have shown that floating net cage (FNC) aquaculture has increased nitrogen and phosphorus inputs into the reservoir, raising trophic status at several locations, particularly around the aquaculture area (Lubis *et al.*, 2024; Siagian & Simarmata, 2018). The continued dominance of *Staurastrum* observed in this study indicates that most of the reservoir's waters still retain mesotrophic characteristics. However, they have begun to experience localized nutrient enrichment due to aquaculture activities. Thus, the plankton community in Koto Panjang Reservoir appears to be in a transitional phase toward more productive conditions but has not yet undergone a full community shift toward the dominance of taxa that generally indicate eutrophication, such as cyanobacteria.

Another implication of ecological decoupling relates to understanding energy flow within the food web. Plankton biomass is directly linked to energy transfer to higher trophic levels, including zooplankton and fish. Therefore, using abundance as the sole indicator can yield less accurate estimates of secondary productivity and energy transfer efficiency. Integrating abundance- and biomass-based approaches is crucial because it provides more comprehensive information on community structure, ecosystem function, and changes in the trophic status of reservoirs (Detmer *et al.*, 2022).

In water quality monitoring practices, plankton abundance is often used as a primary indicator because it is relatively easy to measure and analyze. However, this study indicates that abundance does not always reflect energy distribution within the ecosystem. Communities that appear numerically stable may conceal the dominance of certain species in terms of biomass, which can influence overall ecosystem function (Hillebrand *et al.*, 1999). Therefore, a biomass-based approach is essential to complement abundance-based

interpretations.

In tropical reservoirs such as Koto Panjang, decoupling becomes increasingly significant because of complex environmental pressures, including nutrient enrichment from floating net cage aquaculture (FNC) and climate change. These conditions can accelerate the dominance of species that efficiently utilize resources, widening the discrepancy between abundance and biomass. In the long term, this can affect ecosystem stability, including the potential for harmful algal blooms (Pertiwi *et al.*, 2021; Sharip, 2021; Trismara *et al.*, 2025).

Furthermore, these findings also have implications for fisheries management and aquaculture in reservoirs. High plankton biomass, particularly when dominated by specific species, can affect water quality and the availability of natural food for farmed organisms. Therefore, reservoir management should consider not only plankton abundance but also biomass structure and community composition.

Conceptually, the decoupling phenomenon underscores the importance of a multi-metric approach in aquatic ecology studies. Integrating abundance-based and biomass-based indicators allows for a more comprehensive understanding of community structure and function and provides a stronger foundation for ecosystem management decision-making.

Thus, this study's results not only contribute to our understanding of plankton dynamics in tropical reservoirs but also highlight the limitations of conventional approaches in aquatic ecology. A more integrative approach is needed to accommodate the complexity of ecosystems influenced by interactions between natural and anthropogenic factors.

CONCLUSION

This study shows that the plankton community structure in Koto Panjang Reservoir exhibits distinct spatial patterns along the reservoir's longitudinal gradient: riverine, transitional, and lacustrine zones. Plankton abundance and biomass differ across zones, and an increase in biomass does not always accompany an increase in abundance. This indicates that abundance- and biomass-based approaches represent different ecological aspects within the plankton community.

An abundance-based approach describes the community's numerical structure. It provides a more stable measure of diversity, whereas a biomass-based approach better represents energy distribution and the functional contributions of organisms within the ecosystem. Differences in cell size and species-specific morphological characteristics are the primary factors causing discrepancies between these two approaches.

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