Relationship of eutrophication, phytoplankton and water quality: some generalities in Chanthaburi River, Thailand

Kanisorn Lommetta[1], Sarawut Sangsawangchot[1], Sittipat Paewchum[1] and Jakkapan Potipat[2]*

รับบทความ 24 กันยายน 2568/ ปรับแก้ไข 27 พฤศจิกายน 2568/ ตอบรับบทความ 8 ธันวาคม 2568
Received: September 24, 2025/ Revised: November 27, 2025/ Accepted: December 08, 2025

บทคัดย่อ

การศึกษานี้มุ่งตรวจสอบความสัมพันธ์ของปรากฏการณ์ยูโทรฟิเคชัน ความอุดมสมบูรณ์และความหลากหลายของแพลงก์ตอนพืช และคุณภาพน้ำในแม่น้ำจันทบุรี บริเวณอ่าวไทยฝั่งตะวันออกของประเทศไทย โดยปฏิบัติงานสำรวจภาคสนามบริเวณต้นน้ำ กลางน้ำ และปลายน้ำ ครอบคลุมทั้งฤดูฝน ฤดูหนาว และฤดูร้อน พบแพลงก์ตอนพืชทั้งหมด 191 ชนิด จำแนกทางอนุกรมวิธานครอบคลุม 7 คลาส ส่วนใหญ่คลาส Bacillariophyceae และ Chlorophyceae เป็นคลาสที่มีความโดดเด่น พบว่า Chlorophyceae มีความหนาแน่นสูงสุดบริเวณต้นน้ำในฤดูร้อน ส่วน Bacillariophyceae แพร่กระจายอยู่บริเวณปลายน้ำ ดัชนีเชิงนิเวศ ได้แก่ ดัชนีความหลากหลายของแชนอน–วีเนอร์ และดัชนีความอุดมสมบูรณ์ของมาร์กาเลฟมีค่าสูงสุดที่ต้นน้ำระหว่างฤดูฝน ขณะที่ดัชนีความสม่ำเสมอของพีลูพบค่าสูงสุดบริเวณกลางน้ำในช่วงฤดูร้อน การวิเคราะห์ทางสถิติพบความสัมพันธ์เชิงบวกอย่างมีนัยสำคัญระหว่างปริมาณออกซิเจนละลายน้ำกับดัชนีเชิงนิเวศทั้งหมด ซึ่งเน้นย้ำถึงอิทธิพลของความแปรปรวนทางฟิสิกส์-เคมีและอุทกวิทยาต่อโครงสร้างของชุมชนแพลงก์ตอนพืช โดยภาพรวมตลอดแนวลำน้ำของแม่น้ำจันทบุรีชี้ให้เห็นถึงสถานะทางนิเวศที่ระดับมีโซโทรฟิก

คำสำคัญ: ยูโทรฟิเคชัน แพลงก์ตอนพืช ดัชนีทางนิเวศ คุณภาพน้ำ แม่น้ำจันทบุรี

Abtract

This study investigated on the interrelationships among eutrophication, phytoplankton abundance and diversity, and water quality parameters in the Chanthaburi River, Eastern Gulf of Thailand. Field surveys were conducted at upstream, midstream, and downstream sites during the rainy, winter, and summer seasons. A total of 191 phytoplankton species representing seven taxonomic classes were identified, with Bacillariophyceae and Chlorophyceae the most dominant. Chlorophyceae peaked upstream in summer, while Bacillariophyceae prevailed downstream. Ecological indices Shannon-Wiener's diversity and Margalef's richness were highest at the upstream during the rainy season, whereas Pielou's evenness was maximum at the midstream in summer. Statistical analysis revealed significant positive correlations between dissolved oxygen and all ecological indices, highlighting the influence of physico-chemical gradients and hydrological variation on the community structure of phtoplankton. Overall, the longitudinal profile of Chanthaburi river indicated a mesotrophic ecological status.

Keywords: eutrophication, phytoplankton, ecological index, water quality, Chanthaburi River

[1]Faculty of Agricultural Technology, Rambhai Barni Rajabhat University, Chanthaburi 22000, Thailand
[2]Environmental Science and Technology Program, Faculty of Science and Technology, Rambhai Barni Rajabhat University, Chanthaburi 22000, Thailand
*Corresponding author, E-mail; jakkapan.p@rbru.ac.th

Introduction

Eutrophication refers to the enrichment of water bodies with nutrients, primarily nitrogen and phosphorus, leading to excessive proliferation of phytoplankton and aquatic plants (Ansari et al., 2011). This phenomenon may arise from both natural processes and anthropogenic activities, occurring gradually over geological time or rapidly through human interventions, the latter recognized as cultural eutrophication (Akinnawo et al., 2023). Freshwater eutrophication is primarily caused by anthropogenic inputs, including sewage discharges, detergent use, livestock waste, aquaculture, agricultural runoff, and food-processing effluents (Camargo et al., 2005). The decomposition of extensive phytoplankton blooms induces anoxic conditions, altered biogeochemical cycling, leading to shifts in species diversity, fish mortality, and disruptions of trophic levels (Adams et al., 2020). Blooms of Cyanophyceae contribute to anoxic conditions in the hypolimnion, where hydrogen sulfide is generated, ultimately resulting in odor nuisance and associated toxic effects (Bukowska et al., 2017). Since the mid-20th century, eutrophication has been extensively studied; however, uncertainties remain regarding river evolutionary mechanisms, particularly the ecological determinants of plankton blooms although nutrient enrichment is widely recognized as its primary cause (Du et al., 2019). Several treatments approaches have been introduced to control eutrophication, including the use of chemical coagulants such as lime, magnesium sulphate and ferric sulphate, aimed at protecting aquatic ecosystems (Akinnawo et al., 2023). Environmental scientists and ecologists must give urgent attention to this issue and raise public awareness of its potential ecological and human health impacts.

Aquatic ecosystems are energetically sustained by the autotrophic production of a phylogenetically heterogeneous group of producers known as phytoplankton (Taipale et al., 2016). Across the Land-Ocean Continuum, from rivers and lakes to coastal area and open-ocean, phytoplankton communities seldom comprise a single taxonomic group, and their composition shifts markedly with spatiotemporal environmental variation and anthropogenic inputs (Zhu et al., 2025). Marine phytoplankton significantly regulate Earth's climate by fixing atmospheric CO_2 into organic matter via the biological carbon pump (BCP) and facilitating deep-ocean carbon sequestration (Jiang et al., 2024). Current research on phytoplankton primary productivity has primarily focused on tropical, subtropical, and temperate lakes, with findings demonstrating that it is influenced by water quality and monitoring location (Yu et al., 2022). Phytoplankton growth and population dynamics are strongly influenced by both environmental variables and interactions with surrounding microorganisms. Their succession and decline are mediated through complex microbial relationships, particularly mutualistic mechanisms that significantly regulate the balance between phytoplankton and bacterial communities (Huang et al., 2021). Additionally, phytoplankton are regarded as reliable bioindicators for assessing the degree of water pollution because of their short life cycles, rapid reproduction, abundant taxonomic, wide distribution and sensitivity to environmental factors (Xiong et al., 2016) Hydrological flow events, including river velocity, vertical mixing, estuarine tides, and advection, contribute to the significant heterogeneity of phytoplankton across spatial and temporal scales (Jiang & Xia, 2017). For Thailand, the tropical monsoon climate significantly influences phytoplankton diversity, while the nation also faces mounting challenges from water pollution introduced by anthropogenic activities and the escalating impacts of climate change (Kunpradid et al., 2024). Previous investigations into phytoplankton dynamics and water quality monitoring have largely concentrated on temperate and marine ecosystems, leaving a knowledge gap regarding tropical freshwater eosystems. In regions such as Thailand, where high rainfall, warm temperatures, and humid climatic regimes accelerate nutrient loading and organic matter decomposition, the risk of eutrophication in river, stream and creek is particularly acute. Addressing this challenge requires long-term ecological monitoring that integrates hydrological, physicochemical, biological, and climatic factors (Henson et al., 2021). Bridging this knowledge gap requires an ecological assessment of phytoplankton community structure, functional group dynamics, and water quality indicators within tropical

river regions. Such an approach can yield critical ecological insights that inform adaptive management strategies and foster the sustainable conservation of freshwater species.

Data on their abundance and taxonomic composition provide valuable insights for evaluating anthropogenic impacts on aquatic systems and for monitoring the ecological risk of river. Phytoplankton populations exhibit high sensitivity to variations in water quality and are more easily disturbed than many other aquatic species, making them reliable indicators of pollution and widely applied as bioindicators in riverine environments (Yoon et al., 2024). Water quality parameters such as temperature, salinity and dissolved oxygen were important in influencing the abundance of phytoplankton and functional groups. While oxygen in epilimnion zone (or upper water layer) is consumed through respiration and biochemical processes, its primary source is phytoplankton photosynthesis, with net oxygen production strongly influenced by thermal regime. During the wet season or summer period, elevated temperatures combined with adequate light availability regulated phytoplankton growth, energy flux, enzymatic reactions, reproduction and biomass accumulation. Chlorophyta were more abundant in the wet season, whereas diatoms dominated in the dry season due to their eurythermal tolerance, reflecting their capacity to persist across variable warmer conditions (Gao et al., 2024). Additionally, freshwater and marine species experience strong osmotic stress along salinity gradients, which act as a lethal barrier for many phytoplankton taxa, with different groups adapting to specific salinity ranges from upstream to estuarine areas (Bharathi et al., 2022).

Given the complexity of plankton bloom phenomena, an integrated approach linking phytoplankton abundance and diversity with environmental variability is essential for monitoring ecological dynamics and river health. Our study focuses on phytoplankton abundance and diversity along the Chanthaburi River, Eastern Gulf of Thailand, and emphasizes limnological parameter surveys guided by riverine water quality standards.

Research Methodology

Field sampling

The Chanthaburi River, stretching approximately 120 km, originates in the northern mountains at Khao Khitchakut National Park as the upstream section, flows through the urban community of Chanthaburi as the midstream, and ultimately discharges into the Gulf of Thailand at Laem Sing District as the downstream (**Figure 1; Table 1**). Chanthaburi Province is located within a tropical monsoon climate zone, marked by two primary rainfall periods: a wet season influenced by the southwest monsoon (May-October) and a dry season associated with the northeast monsoon (December-February), which collectively account for about 85% of the total annual precipitation. Climate records indicate an average annual rainfall of 455.2 mm, based on data from two rain gauge stations, with a mean annual temperature of approximately 29°C (Thai Meteorological Department, 2024).

Table 1. Comparison of river longitudinal profile characteristics across different zones

River longitudinal profile	Upstream	Midstream	Downstream
Topography	Watershed, mountain, piedmont plain	Lowland plain, floodplain, meandering river	Estuary, mangrove, coastal plain, tidal flat
Land use	Headwater catchment, forest land, national park, reservoir and cultivated orchard	Multiple anthropogenic sources: urban sewage, residential expansion, transportation	Fisheries, aquaculture, eco-tourism accommodation (Homestay)

Water sampling and physicochemical analysis

Phytoplankton and water samples were collected from the epilimnion zone (0.5-1.0 m) during December 2023, March 2024, and June 2024, corresponding to the winter, summer, and rainy seasons, respectively. All ecological samples were collected in triplicate. To minimize the influence of light variation on phytoplankton communities, all sampling was conducted during daylight hours.

The identification of phytoplankton diversity was performed at the Aquaculture Laboratory, Faculty of Agricultural Technology, Rambhai Barni Rajabhat University, following the procedure illustrated in **Figure 2.**

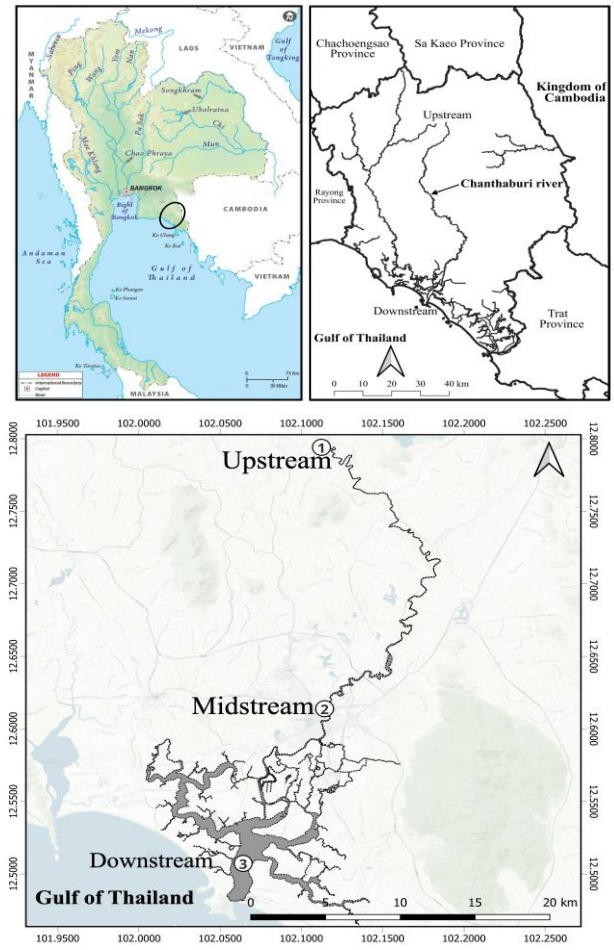


Figure 1. Map of study location in Chanthaburi River, Chanthaburi Province, Thailand

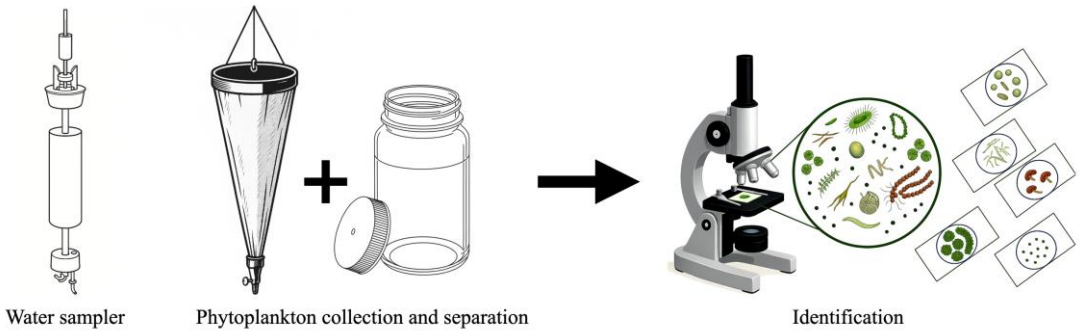


Figure 2. Procedure for phytoplankton studies

A vertical water samples were collected by using a Kemmerer and combined across the water column for subsequent water quality analysis. The float method estimates flow rate in open channels by recording the travel time of a floating object over a measured distance and calculating surface velocity as distance divided by time (Marjang & Merkley, 2009). River current speed was determined by timing the drift of a golf ball across a fixed distance (m) using a stopwatch (s), and was calculated according to the equation:

Current velocity (m/s) = Fixed distance (m) ÷ Time (s)

The temperature was recorded using a thermometer integrated with the sampler. Physicochemical parameters were measured in situ using a multiple electrode meter (AZ Instrument Model 86031), whereas dissolved oxygen was fixed in the field and subsequently analyzed in the laboratory following the Winkler method.

Phytoplankton identification

Phytoplankton samples were collected by filtering 50 L of water sampling within the depth range of 0.5-1.0 m through a plankton net with a mesh size of 21 µm. The samples were preserved with formalin at a final concentration of 4%. Identification and enumeration were conducted using a Sedgewick-Rafter counting chamber under a compound microscope. Taxonomic identification followed phytoplankton identification manual (Desikachary, 1959; Prescott, 1962) and the online database of AlgaeBase (https://www.algaebase.org).

Ecological indices for phytoplankton diversity assessment

Environmental stress generally decreases the taxonomic diversity of river communities, while eutrophication often induces extensive blooms dominated by a few highly abundant phytoplankton species. This study applied three ecological diversity metrics, Shannon-Wiener's index, Pielou's evenness index and Margalef's richness index to assess the composition and distribution of phytoplankton communities based on raw data recorded through microscopic identification.

The density of phytoplankton

Phytoplankton density in the water samples was observed using a slide counting chamber, and the total number of phytoplankton per litre of water was calculated using the following equation (Gireesh et al., 2015) :

$$N = nv/V$$

Where N is total amount of phytoplankton per litre, n is the average amount of phytoplankton in 1 ml of samples, v is water volume in sampling bottle (ml) and V is the volume of water filtered (l).

Diversity index

The diversity index reflects the structural complexity and distribution of genera within a population and was evaluated for phytoplankton communities using the Shannon-Wiener's index (Gusmaweti & Deswati, 2018), as shown in the following equation:

$$H' = -\sum_{i=1}^{n} p_i \ln(p_i)$$

Where

H′ = Shannon-Wiener's index

pi = The proportion of type i within population (i = 1, 2, 3, ... n)

Evenness index or equitability

The equitability index, also known as Pielou's evenness index, evaluates how evenly species are distributed within a sampling site relative to a perfectly even distribution (Niyoyitungiye et al., 2020), and is calculated using the following equation:

$$E = H'/\ln S$$

Where

E = Evenness index

H′ = Shannon-Wiener's index

S = Total number of phytoplankton species

Species richness index

The species richness index indicates habitat suitability for biota, with higher values signifying greater biodiversity, complex trophic structures, and enhanced community stability (Margalef, 1967). Additionally, the Margalef richness index has no upper limit and varies with the number of species, as calculated by:

$$D = (S - 1)/\ln N$$

Where

D = Diversity index

S = Number of phytoplankton species within the sample

N = Total count of all phytoplankton individuals across all species within the sample

Statistical analysis

Phytoplankton abundance differences in response to seasonal and spatial variables were evaluated using ANOVA. Pearson's correlation coefficient was applied to evaluate the relationships between ecological indices and water quality variables. All statistical analyses were performed using JAMOVI (version 2.7.11; Jamovi, 2025), with a significance level set at *0.05* for all tests. Hierarchical cluster analysis using Ward's method was performed on standardized phytoplankton abundance data to determine inter-class similarity.

Results and Discussion

Abundance and composition of phytoplankton

The results showed that the average phytoplankton density was highest in the rainy season, with 1,132.67 units/l, followed by winter and summer, with values of 591.33 and 448.67 units/l, respectively (**Figure 3**). The highest mean density occurred at the downstream site (843.67 units/l), whereas lower densities were recorded at the upstream (809.67 units/l) and the midstream sites (519.33 units/l), respectively. One-way ANOVA revealed no significant seasonal variation in phytoplankton density among rainy, winter and summer periods (*F=0.9903; p > 0.05*), and longitudinal comparison using the *F*-test similarly indicated no statistically significant differences between sampling sites (*F=0.2767; p > 0.05*). The present

findings indicate that phytoplankton density revealed seasonal variation, with peak abundance during the rainy season and lower densities in the winter and summer periods. This pattern suggests that hydrological regimes, particularly rainfall runoff or erosion, play a crucial role in nutrient transportation and phytoplankton proliferation within tropical rivers (Reynolds, 2006). Downstream sites generally supported higher densities compared to upstream and midstream zones, reflecting the cumulative input of nutrients and organic loading across the longitudinal gradient of the river. Despite these trends, statistical analysis (ANOVA and *F*-test) revealed no significant differences among seasons and sampling sites, indicating a tendency that environmental variations to be buffered by ecological processes such as nutrient recycling and self-purification (Tilman et al., 1982).

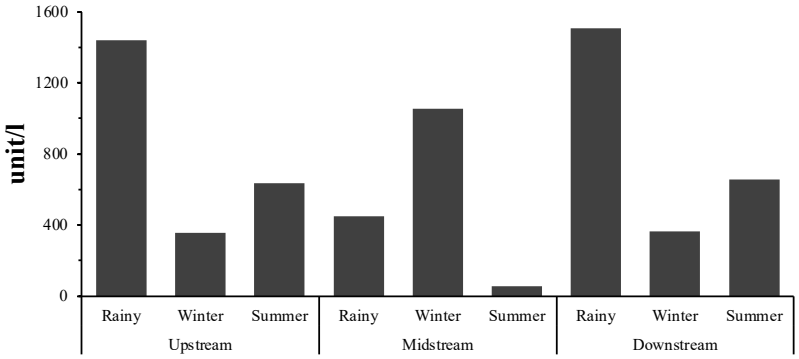


Figure 3. phytoplankton density at each sampling site during different seasonal periods

A total of 191 phytoplankton species were surveyed and recorded from the Chanthaburi River, spanning three divisions: Chromophyta, Chlorophyta and Cyanophyta, whose abundance and composition were also classified into 7 classes, 18 orders, 44 families and 99 genera, as presented in **Table 2**.

Table 2. The identified phytoplankton genera and their taxonomic classification from the Chanthaburi River

Classes	Genera
Bacillariophyceae	*Melosira, Aulaccosira, Coscinodiscus, Guinardia, Pseudosolenia, Rhizosolenia, Climacodium, Odontella, Triceratium, Synedra, Thalassionema, Thalassiothrix, Grammatophora, Striatella, Climacsphenia, Eunotia, Cymbella, Gomphonema, Amphipleura, Amphora, Diploneis, Frustulia, Gyrosigma, Navicula, Neidium, Pinnularia, Pleurosigma, Sellaphora, Stauroneis, Bacillaria, Entomoneis, Nitzschia, Pseudo-Nitzschia, Epithemia, Rhopalodia, Plagioduscus, Surirella, Hemiaulus, Chaetoceros, Bacteriastum*
Chlorophyceae	*Eudorina, Pandorina, Volvox, Asterococcus, Pediastrum, Coelastrum, Botryococcus, Ankistrodesmus, Closteriopsis, Chlorella, Dictyosphaerium, Dimorphococcus, Kirchneriella, Lagerheimia, Nephrocytium, Oocystis, Schroederia, Tetraedron, Micractinium, Scenedesmus, Geminella, Ulotrix, Mougeotia, Spirogyra, Gonatozygon, Closterium, Cosmarium, Desmidium, Eurastrum, Micrasterias, Plerotaenium, Sphaerozosma, Spondylosium, Staurastrum, Xanthidium, Arthrodesmus*
Dinophyceae	*Prorocentrum, Dinophysis, Noctiluca, Ceratium, Gonyaulax, Pyrophacus, Peridinium, Protoperidinium*
Euglenophyceae	*Euglena, Lepocinclis, Phacus, Strombomonas, Tracheromonas*
Cyanophyceae	*Chroococcus, Microcystis, Oscillatoria, Spirulina, Trichodesmium, Tolypothrix, Scytonema*
Chrysophyceae	*Dinobryon, Mallomonas*
Dictyochophyceae	*Dictyocha*

At the community level, Bacillariophyceae and Chlorophyceae dominated the assemblages, consistent with their ecological adaptability and tolerance to varying nutrient regimes. The occurrence of

Cyanophyceae, though in lower numbers, may serve as an indicator of potential eutrophication risk, as observed in other tropical lotic ecosystems (Padisák et al., 2009). These findings align with previous studies demonstrating the sensitivity of phytoplankton assemblages to both seasonal hydrology and spatial gradients, thereby underscoring their value as bioindicators for assessing ecological integrity and water pollution in the rivers (Dokulil & Teubner, 2012). Additionally, the distribution of phytoplankton populations is influenced by abiotic factors as follows: (i) preference for inhabiting low-light conditions (<1%) and cool water temperatures (5-12°C) within the metalimnion, where steep density gradients and reduced turbulence occur, (ii) survival in or below the thermocline is facilitated by phytoplankton through physiological acclimation of photosynthetic activity and buoyancy regulation, while persistence during stratified periods is further supported by a potential heterotrophic mode of subsistence and (iii) climate warming exerts temporally and seasonally variable effects on phytoplankton communities, with benefits largely confined to winter and weakly transmitted into spring and early summer during the transition to water stratification.

Figure 4 revealed that the Cluster 1 was dominated by both Chlorophyceae and Bacillariophyceae, with Chlorophyceae being more abundant in the upstream sites during the summer, whereas Bacillariophyceae were dominant in the downstream sites during the rainy season. Euglenophyceae proliferate in freshwater conditions with low salinity and high nutrient availability, serving as a biological indicator of organic contamination in inland aquatic ecosystems (Nhien & Giao, 2024). Charophyta are most abundant within wetland littoral zones, where they strongly influence phytoplankton assemblages and display notable spatial and temporal fluctuations in density. Similarly, other groups, including Dinozoa, Chrysophyta, Cyanobacteria, and Bacillariophyta, each contribute to phytoplankton dynamics across these zones and indicate notable variability across regions and seasons (Sharma & Sharma, 2022).

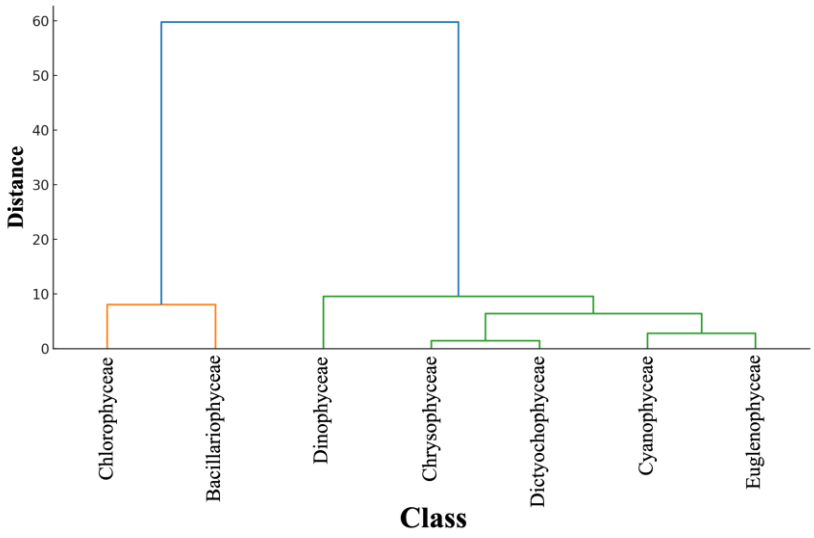


Figure 4. Hierarchical cluster analysis of phytoplankton classes showing ecological groupings of taxa

Ecological indices assessment for phytoplankton characterization

The ecological indices are commonly used to characterize phytoplankton communities because they integrate species diversity data into a single metric, facilitating comparisons of population structure under varying environmental factors. Numerous studies adopting diverse approaches have underscored the pivotal role of autotrophic community diversity in sustaining ecosystem functioning (Henson et al., 2021).

The Shannon-Wiener's index values assessed in this study range from 1.50-3.40, while Pielou's evenness index and Margalef richness index showed 0.51-0.92 and 2.01-9.32, respectively. Based on the

ecological indices reported in **Table 3** and their classification criteria of ecological indices in **Table 4**, clear spatial and temporal variations were observed in phytoplankton community structure. Shannon-Wiener's index indicated higher diversity at the downstream zones during the winter (3.18) to summer (3.07) seasons, while the rainy season, upstream (3.40) and midstream (3.10) zones were also classified as "high diversity". In contrast, a "very low" status was recorded in the downstream and midstream zones during the rainy (1.96) and winter (1.50) seasons, respectively. Pielou's evenness index indicated that phytoplankton assemblages were generally classified as "almost balanced" (0.76-0.95), except at upstream, midstream, and downstream zones during the summer, winter, and rainy seasons, respectively, exhibited "semi-balanced" conditions, suggesting community heterogeneity in the riverine ecosystem studied. Margalef's richness index revealed substantially greater species richness during the rainy and summer seasons (>5.0, categorized as "high species richness"), whereas values declined markedly in the winter at upstream (3.24) and midstream (2.01) zones, corresponding to a "low species richness" status.

Diversity and richness indices were highest in the upstream site during the rainy season, whereas the evenness index peaked in the midstream over the summer period. In contrast, the winter season displayed the lowest diversity and richness indices in the midstream site. These findings provide valuable insights into patterns of phytoplankton diversity, abundance and species richness, contributing to our understanding of the consequences of anthropogenic contamination, regional influences, seasonal succession and nutrient enrichment. Ecological indices are widely applied to assess plankton community structure and evaluate river nutrient enrichment across varying environmental cycles, serving as key indicators for determining the degree of water pollution.

Table 3. Ecological indices assessment of phytoplankton community in the study

Ecological indices	Rainy			Winter			Summer		
	Up	Mid	Down	Up	Mid	Down	Up	Mid	Down
Shannon-Wiener's index	**3.40**	3.10	1.96	2.30	1.50	3.18	2.47	2.71	3.07
Pielou's evenness index	0.84	0.76	0.51	0.77	0.57	0.84	0.63	**0.92**	0.78
Margalef richness index	**9.32**	9.10	6.01	3.24	2.01	5.91	7.18	4.47	8.03
Density (unit/l)	358	651	**1,509**	354	634	1,441	1,048	56	448

Table 4. Classification criteria of ecological indices and their status in the riverine ecosystems

Values of ecological index	Phytoplankton status
Shannon-Wiener's index	
> 3.5	Very high
3.0 - 3.5	High
2.5 - 2.9	Moderate
2.0 - 2.4	Low
< 2.0	Very low
Pielou's evenness index	
0.96 - 1.0	Balanced
0.76 - 0.95	Almost balanced
0.51 - 0.75	Semi-balanced
0.26 - 0.50	Less balanced
0.00 - 0.25	Unbalanced
Margalef richness index	
> 5.0	High species richness
2.5 - 4.9	Medium species richness
< 2.5	Low species richness

Source: (Napaldet, 2023)

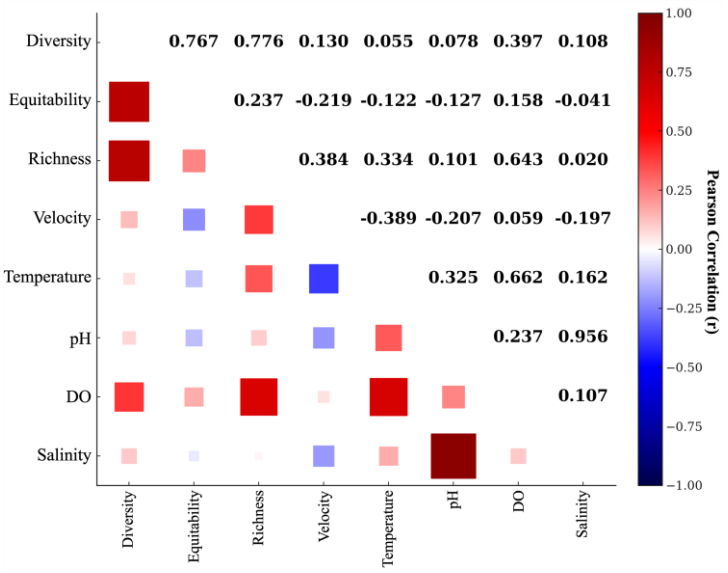


Figure 5. Pearson's correlation coefficient between different ecological indices and water quality parameters along the Chanthaburi River

Positive correlations were observed among Shannon-Wiener's index, Pielou's evenness index and Margalef richness index along the longitudinal of the Chanthaburi River (**Figure 5**), reflecting consistent ecological sensitivity across these diversity metrics. These findings align with phytoplankton studies in Mediterranean coastal sub-regions, where ecological indices effectively distinguished anthropogenic impacts, and correlations between diversity, evenness and richness metrics revealed strong, positive relationships (Francé et al., 2021). Additionally, the relationship between phytoplankton density and the Shannon–Wiener's index within the conservation area of southwestern Vietnam's Mekong Delta reflected ecological dynamics and classified the surface water quality as ranging from moderate to heavy pollution (Nhien & Giao, 2024).

Physicochemical water quality and eutrophication

Water quality investigation of the epilimnion layer in the Chanthaburi River revealed temperature, pH, dissolved oxygen (DO) and salinity ranges of 28.1 to 32.2 °C, 5.83 to 7.88, 4.0 to 7.9 mg/l and 0.03 to 24.80 ppt, respectively. **Figure 6** shows the variations in these physicochemical parameters, with pH and DO levels compared against Thailand's surface water quality standards (Pollution Control Department: PCD, 1994). Additionally, flow velocity peaked during the rainy season, gradually decreased through winter, and reached its lowest levels in summer, reflecting seasonal hydrodynamic variation in the riverine area.

Seasonal physicochemical variability in surface waters of Chiang Mai, Thailand, revealed that four major parameters differed significantly ($p < 0.05$) across seasonal transitions, underscoring the influence of hydrological regimes on aquatic conditions. During the dry season, reductions in discharge and water volume tend to elevate concentrations of organic matter, whereas in the wet season, intensified rainfall promotes surface runoff that mobilizes eroded-soil particles enriched with phosphorus, thereby contributing to nutrient loading and potential eutrophication processes within riverine ecosystems (Kunpradid et al., 2024).

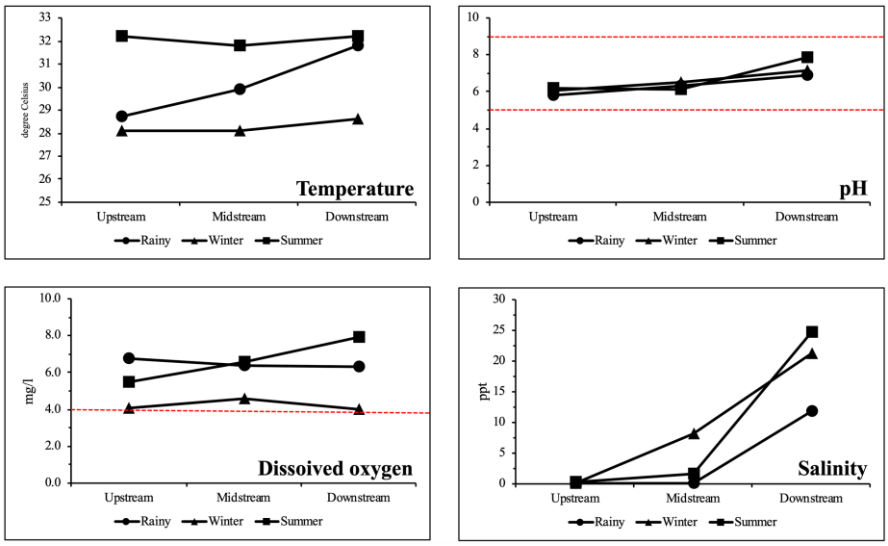


Figure 6. Physicochemical parameters in the longitudinal zone of Chanthaburi River

pH and salinity exhibited a very strong positive correlation (**Figure 5**), with shifts from neutral to acidic conditions influencing phytoplankton community composition, growth rates, biomass, and cell morphology in freshwater ecosystems. Phytoplankton biomass declined with increasing salinity; however, salinity levels below 3.0 ppt showed no observable effects on cell morphology. Elevated salinity primarily reduced cell height, while cell diameter remained relatively stable (Chakraborty et al., 2021). Moreover, the river-estuary continuum transports salinity gradients, with transitional zones often exhibiting pronounced variation in phytoplankton composition along the freshwater: upstream; saltwater: downstream (Wang & Zhang, 2020). DO showed a positive correlation with all ecological indices (**Figure 5**), and is an essential factor to maintaining trophic balance, which varies both geographically and seasonally. Seasonal fluctuations influence phytoplankton abundance, contributing to variations in the DO sag curve, with concentrations naturally oxygenated through photosynthesis but consumed by respiration and organic matter degradation. Additionally, excessive phytoplankton biomass can produce organic material that further exacerbates DO depletion. The finding indicated that DO showed no clear seasonal trend, with levels typically lowest in winter and gradually increasing during rainy and summer periods. However, shifts in phytoplankton community structure were strongly influenced by DO across most sampling sites in both lentic and lotic ecosystems, regulated by water column stratification and light availability (Cui et al., 2023).

Succession of phytoplankton community composition, particularly the transition in dominance from diatoms to non-motile taxa and flagellates, reflect changes in physiological traits and ecological functions that serve as key indicators of eutrophication (Dutta et al., 2023). DO consumptions often reflect eutrophication and organic matter decomposition along the upstream-downstream gradient, influenced by natural self-purification processes (Huang et al., 2019). Phytoplankton respond rapidly to environmental changes, making them critical bioindicators for assessing the state of fluvial ecosystems and the degree of water pollution. Our results showed that dominant phytoplankton assemblages in the upstream, midstream, and downstream zones are closely associated with water quality variations and can serve as reliable bioindicators for assessing eutrophication risk, as shown in **Figure 7**. These dominant taxa not only reflect eutrophication and environmental quality but also serve as effective bioindicators for identifying indirect abiotic effects of water pollution. For example, Nitzschia and Pseudo-nitzschia are both genera of diatoms, with the latter known for producing domoic acid (DA), a neurotoxin that cause amnesic shellfish poisoning (Meerssche et al., 2018). Tracheromonas was observed predominantly in the dry season, associated with

high concentrations of organic matter, nitrogen, phosphorus, and warm water temperatures (Solórzano et al., 2011); while Chaetoceros, a marine diatom commonly utilized as aquaculture feed, is recognized for its rapid growth, ease of cultivation, and tolerance to elevated temperatures (33-35 °C) (Minggat et al., 2021).

Conclusions

This study successfully characterized phytoplankton diversity along the longitudinal profile of the Chanthaburi River, a euphotic zone supporting dynamic phytoplankton communities, using aquatic ecological indices as new scientific evidence. The Shannon-Wiener index (1.50-3.40), Pielou's evenness (0.51-0.92), and Margalef richness (2.01-9.32) highlighted clear seasonal and spatial variations, with diversity and richness peaking upstream during the rainy season and evenness highest in the midstream during summer period. These results confirmed the study's goal by demonstrating that phytoplankton are reliable bioindicators for assessing ecological balance and reflecting spatio-temporal variations in the water quality. Positive correlations among ecological indices and dissolved oxygen further emphasized their ecological sensitivity. However, while the study clarified phytoplankton community responses, it did not extend to higher trophic levels. Future research should address this gap by linking phytoplankton-based indices with zooplankton, periphyton, benthos, nekton, and other biotic components to provide a more integrated understanding of trophic interactions and ecosystem productivity along riverine-estuarine environments.

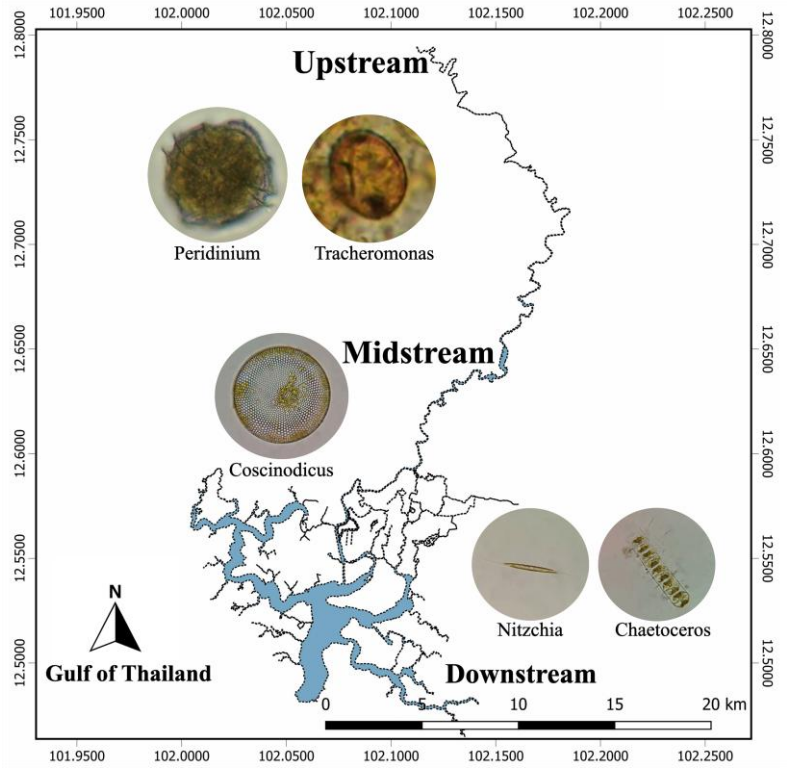


Figure 7. Distribution of dominant phytoplankton along the longitudinal profiles of the Chanthaburi River

Acknowledgements

We express our sincere gratitude to the Faculty of Agricultural Technology, Rambhai Barni Rajabhat University, Chanthaburi Province, Thailand for kindly providing the facilities and equipment for carrying out this research. Finally, we extend our deepest appreciation to all individuals and collaborators who contributed to the successful completion of this project.

Funding

The research team would like to express sincere gratitude to the National Science, Research and Innovation Fund, Thailand Science Research and Innovation (TSRI), Fiscal Year 2023, for supporting the research grant in response to the Plant Genetic Conservation Project Under the Royal Initiative of Her Royal Highness Princess Maha Chakri Sirindhorn (RSPG).

References

Adams, J., Taljaard, S., van Niekerk, L., & Lemley, D.A. (2020). Nutrient enrichment as a threat to the ecological resilience and health of South African microtidal estuaries. *African Journal of Aquatic Science, 45*(1-2), pp.23-40.

Akinnawo, S.O. (2023). Eutrophication: Causes, consequences, physical, chemical and biological techniques for mitigation strategies. *Environmental Challenges*, *12*, p.100733. https://doi.org/10.1016/j.envc.2023.100733

Ansari, A.A., Gill, S.S., & Khan, F.A. (2011). Eutrophication: Threat to aquatic ecosystems. In Ansari, A.A., & Gill, S.S. (Eds.), *Eutrophication: Causes, consequences and control* (pp.143-170) Dordrecht : Springer.

Bharathi, M.D., Venkataramana, V., & Sarma, V.V.S.S. (2022). Phytoplankton community structure is governed by salinity gradient and nutrient composition in the tropical estuarine system. *Continental Shelf Research, 234*, p.104643. https://doi.org/10.1016/j.csr.2021.104643

Bukowska, A., Kaliński, T., Koper, M., Kostrzewska-Szlakowska, I., Kwiatowski, J., Marzec, H.M., & Jasser, I. (2017). Predicting blooms of toxic cyanobacteria in eutrophic lakes with diverse cyanobacterial communities. *Scientific Reports, 7*(1), pp.1–12.

Camargo, J.A., Alonso, Á., & Puente, M. (2005). Eutrophication downstream from small reservoirs in mountain rivers of Central Spain. *Water Research, 39*(14), pp.3376-3384.

Chakraborty, S., Karmaker, D., Rahman, Md.A., Bali, S.C., Das, S.K., & Hossen, R. (2021). Impacts of pH and salinity on community composition, growth and cell morphology of three freshwater phytoplankton. *Plant Science Today, 8*(3), pp.655-661.

Cui , Z., Gao, W., Li, Y., Wang, W., Wang, H., Liu, H., Fan, P., Fohrer, N., & Wu, N. (2023). Dissolved oxygen and water temperature drive vertical spatiotemporal variation of phytoplankton community: evidence from the largest diversion water source area. *International Journal of Environmental Research and Public Health, 20*(5), p.4307. https://doi.org/10.3390/ijerph20054307

Desikachary, T.V. (1959). *Cyanophyta.* New Delhi : Indian Council of Agricultural Research. pp.12-686.

Dokulil, M.T., & Teubner, K. (2012). Deep living *Planktothrix rubescens* modulated by environmental constraints and climate forcing. *Hydrobiologia, 698*, pp.29-46.

Du, H., Chen, Z., Mao, G., Chen, L., Crittenden, L., Li, R.Y.M., & Chai, L. (2019). Evaluation of eutrophication in freshwater lakes: A new non-equilibrium statistical approach. *Ecological Indicators, 102*, pp.686-692.

Dutta, S., Dhan, S.A., Uddin, Sk.N., & Saha, B. (2023). Phytoplankton as an indicator of eutrophication. *Ecology, Environment and Conservation, 29*(3), pp.1042-1052.

Francé, J., Varkitzi, I., Stanca, E., Cozzoli, F., Skejic, S., Ungaro, N., Vascotto, I., Mozetic, P., Gladan, Z.N., Assimakopoulou, G., Pavlidou, A., Zervoudaki, S., Pagou, K., & Basset, A. (2021). Large-scale testing of phytoplankton diversity indices for environmental assessment in Mediterranean sub-regions (Adriatic, Ionian and Aegean Seas). *Ecological Indicators, 126*, p.107630. https://doi.org/10.1016/j.ecolind.2021.107630

Gao, W., Xiong, F., Lu, Y., Xin, W., Wang, H., Feng, G., Kong, C., Fang, L., Gao, X., & Chen, Y. (2024). Water quality and habitat drive phytoplankton taxonomic and functional group patterns in the Yangtze River. *Ecological Processes, 13*, p.1-15.

Gireesh, R., Varghese, M., & Thomas. V.J. (2015). *Phytoplankton - collection, estimation, classification and diversity.* Kochi : Central Marine Fisheries Research Institute.

Gusmaweti, & Deswati, L. (2018). Community structure, phytoplankton density and physicalchemical factor of batang palangki waters of sijunjung regency, west sumatera. *IOP Conference Series: Earth and Environmental Science*, *130*, p.012023.

Henson, S.A., Cael, B.B., Allen, S.R., & Dutkiewicz, S. (2021). Future phytoplankton diversity in a changing climate. *Nature Communications, 12*, p.5372.

Huang, B., Wei, N., Hu, Y., & Mao, H. (2021). Microbial communities in water during red tides along the coast of China-A case study of Prorocentrum Donghaiense red tide in the East China Sea. *Journal of Marine Science, 3*(1), pp.29-38.

Huang, G., Xue, H., Liu, H., Ekkawatpanit, C., & Sukhapunnapha, T. (2019). Duality of seasonal effect and river bend in relation to water quality in the Chao Phraya River. *Water, 11*(4), p.656. https://doi.org/10.3390/w11040656

Jiang, H.B., Hutchins, D.A., Zhang, H.R., Feng, Y.Y., Zhanng, R.F., Sun, W.W., Ma, W., Bai, Y., Wells, M., He, D., Jiao, N., Wang, Y., & Chai, F. (2024). Complexities of regulating climate by promoting marine primary production with ocean iron fertilization. *Earth-Science Reviews, 249*, p.104675.

Jiang, L., & Xia, M. (2017). Wind effects on the spring phytoplankton dynamics in the middle reach of the Chesapeake Bay. *Ecological Modelling, 363*, pp.68-80.

Kunpradid, T., Chaimongkhon, P., & Tagun, R. (2024). Seasonal dynamics and environmental drivers of phytoplankton composition in a tropical dam over 5 years in Chiang Mai, Thailand. *Trends in Science, 21*(8), p.7930. https://doi.org/10.48048/tis.2024.7930

Margalef, R. (1967). Some concepts relative to the organization of plankton. *Oceanography and Marine Biology - An Annual Review, 5*, pp.257-289.

Marjang, N., & Merkley, G.P. (2009). Surface velocity coefficients for application of the float method in rectangular and compound open channels. *Irrigation Science, 27*, pp.457-470.

Meerssche, E.V., Greenfield, D.I., & Pinckney, J.L. (2018). Coastal eutrophication and freshening: Impacts on *Pseudo-nitzschia* abundance and domoic acid allelopathy. *Estuarine, Coastal and Shelf Science*, *209*, pp.70-79. https://doi.org/10.1016/j.ecss.2018.05.013

Minggat, E., Roseli, W., & Tanaka, Y. (2021). Nutrient absorption and biomass production by the marine diatom Chaetoceros Muelleri: effects of temperature, salinity, photoperiod, and light intensity. *Journal of Ecological Engineering, 22*(1), pp.231-240. https://doi.org/10.12911/22998993/129253

Napaldet, J.T. (2023). Plant species and ecosystem diversity along national road in mountain sites: The case of Kennon Road in Cordillera Central Range, Philippines. *Taiwania, 68*(3), pp.339-348.

Nhien, H.T.H., & Giao, N.T. (2024). Evaluation of surface water quality using biodiversity indices in phu my species- habitat conservation area, Kien Giang Province, Vietnam. *Ecological Engineering & Environmental Technology, 25*(3), pp.102-112. https://doi.org/10.12912/27197050/178386

Niyoyitungiye, L, Giri, A., & Mishra, B.P. (2020). Quantitative and qualitative analysis of phytoplankton population in relation to environmental factors at the targeted sampling stations on the Burundian littoral of Lake Tanganyika. *International Journal of Fisheries and Aquatic Studies, 8*(1), pp.110-121.

Padisák, J., Crossetti, L.O., & Naselli-Flores, L. (2009). Use and misuse in the application of the phytoplankton functional classification: A critical review with updates. *Hydrobiologia, 621*(1), pp.1-19.

Prescott, G.W. (1962). *Algae of the Western Great Lake Area*. Dubuque Iowa : WM. C. Brown Company Publisher.

Reynolds, C.S. (2006). *Ecology of phytoplankton.* Cambridge : Cambridge University Press.

Sharma, B.K., & Sharma, S. (2022). Phytoplankton diversity of a demineralized urban wetland of Meghalaya State of Northeast India: The spatio-temporal variations and the role of abiotic factors. *Research in Ecology, 4*(2), pp.3-23.

Solórzano, G.G., Martinez, M.G.O., Vazquez, A.L., Garfias, M.B.M., Zuñiga, R.E.Q., & Conforti, V. (2011). Trachelomonas (Euglenophyta) from a eutrophic reservoir in Central Mexico. *Journal of Environmental Biology, 32*, pp.463-471.

Taipale, S.J., Vuorio, K., Strandberg, U., Kahilainen,K.K., Järvinen, M., Hiltunen, M., Peltomaa, E., & Kankaala, P. (2016). Lake eutrophication and brownification downgrade availability and transfer of essential fatty acids for human consumption. *Environment International, 96*, pp.156-166.

Thai Meteorological Department. (2024). *Annual weather summary 2024.* Bangkok : Ministry of Digital Economy and Society.

Tilman, D., Kilham, S.S., & Kilham, P. (1982). Phytoplankton community ecology: The role of limiting nutrients. *Annual Review of Ecology and Systematics, 13*, pp.349-372.

Wang, J., & Zhang, Z. (2020). Phytoplankton, dissolved oxygen and nutrient patterns along a eutrophic river-estuary continuum: Observation and modeling. *Journal of Environmental Management, 261*, p.110233.

Xiong, W., Li, J., Chen, Y., Shan, B., Wang, W., & Zhan, A. (2016). Determinants of community structure of zooplankton in heavily polluted river ecosystems. *Scientific Reports, 6*, pp.22043-22053.

Yoon, S.J., Lee, J., Kim, H.G., Kwon, B.O., Kim, J., Hong, S., & Khim, J.S. (2024). Phytoplankton assemblage responses to massive freshwater inputs and anthropogenic toxic substances contamination in the Geum River Estuary, South Korea. *Marine Pollution Bulletin, 199*, p.116020. https://doi.org/10.1016/j.marpolbul.2023.116020

Yu, H., Shi, X., Zhao, S., Sun, B., Liu, Y., Arvola, L., Li, G., Wang, Y., Pan, X., Wu, R., & Tian, Z. (2022). Primary productivity of phytoplankton and its influencing factors in cold and arid regions: A case study of Wuliangsuhai Lake, China. *Ecological Indicators, 144*, p.109545. https://doi.org/10.1016/j.ecolind.2022.109545

Zhu, Y., Miao, Q., Lyu, H., Zheng, Y., Liu, W., Li, Y., Li, J., Chen, F., & Miao, S. (2025). An approach for mapping phytoplankton communities in freshwater lakes based on phytoplankton absorption features. *Water Research, 282*, p.123665. https://doi.org/10.1016/j.watres.2025.123665