Seasonal Diversity and Abundance of Phytoplankton Influenced by Physicochemical Parameters in the Lower River Benue

Abstract

This study investigates the seasonal diversity and abundance of phytoplankton in the Lower River Benue, influenced by various physicochemical parameters. The research was conducted over an 18-month period, from January 2020 to June 2021, across three sampling sites: Lau, Mayo-Ranewo, and Ibi. Phytoplankton samples were collected monthly, covering both dry and wet seasons, and analyzed for diversity and abundance. Concurrently, water quality parameters such as temperature, pH, turbidity, electrical conductivity, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), hardness, fluoride, and nitrate were measured. The results indicated significant seasonal variations in phytoplankton distribution, with higher abundance during the wet season due to increased water flow and nutrient input from runoff. Key species identified included *Microcystis flos-aquae, Euglena gracilis*, and *Spirogyra sp.,* which collectively contributed to nearly half of the total phytoplankton abundance. The study also revealed that physicochemical parameters such as temperature, pH, and nutrient concentrations directly influenced phytoplankton diversity and abundance. Principal Component Analysis (PCA) highlighted the correlations between environmental parameters and phytoplankton distribution, showing that temperature negatively correlated with turbidity and nitrate, while BOD had a significant negative correlation with fluoride and nitrate. This research provides valuable insights into the ecological processes governing the Lower River Benue and underscores the importance of monitoring water quality to develop effective water resource management strategies.

Introduction

Water is a fundamental element of life, comprising 50–90% of living organisms and covering nearly 75% of the Earth's surface, making it crucial for all forms of life (Chakraborty, 2021). However, the rising pace of urbanization, industrialization, and modernization increasingly threatens the quality of natural water sources (Chakraborty, 2021). Specifically, the extensive use of fertilizers, pesticides, and other agrochemicals has significantly contaminated natural water sources with various harmful pollutants (Odewale et al., 2023). The Lower River Benue, a vital waterway in Nigeria, represents a dynamic ecosystem whose seasonal variations influence various biological and physicochemical processes.

Phytoplankton, key primary producers in aquatic ecosystems, play an essential role in sustaining the aquatic food web and serve as indicators of water quality and ecosystem health (Dong et al., 2022). Seasonal changes, driven by variations in rainfall, temperature, and water flow, create distinct environmental conditions that affect phytoplankton communities (Williamson & Neale, 2022). During the wet season, increased water flow and nutrient input from runoff can lead to higher phytoplankton productivity and diversity (Trombetta et al., 2019). Conversely, the dry season often results in reduced water levels and nutrient availability, impacting phytoplankton abundance and composition (Dong et al., 2022). Key physicochemical parameters, including temperature, pH, dissolved oxygen, and nutrient concentrations, fluctuate with seasonal changes, directly influencing phytoplankton diversity and abundance (Lundsør et al., 2022)

Despite the ecological importance of the Lower River Benue, limited studies have focused on how seasonal variations in physicochemical conditions affect phytoplankton diversity and abundance in this river system. This study seeks to address this gap by examining phytoplankton patterns across seasons, providing insights into the ecological processes that govern this vital river system. Understanding these dynamics is essential for developing effective water resource management strategies to protect and sustain the health of Nigeria's riverine ecosystems. Through this research, we aim to contribute valuable knowledge that can guide sustainable conservation efforts and improve our understanding of human impacts on freshwater systems.

2. Materials and Methods

2.1 Study Area

The River Benue is a freshwater river that flows through Nigeria and is the country's second-largest river. The river originates from the Adamawa mountains of Cameroun, some bounding the Nigeria frontier, and flows eastward through the Nigeria territory before joining the River Niger at Lokoja, Kogi state, Nigeria (Okayi *et al*., 2001). This research was conducted in Taraba State North Eastern Nigeria. Taraba State, located at 8º 00' N, 10º 30' E in central Nigeria, covers an area of 54,473 km² and had a population of 2,294,800 in the 2006 census. Its landscape is mostly undulating, highlighted by the scenic Mambilla Plateau.

The study locations include Ibi, Lau, and Mayo-Ranewo, each situated in Taraba State, Nigeria, along the River Benue. Ibi, a town and administrative district, lies on the river's south bank and is near the confluence of the Taraba, Donga, and Shemankar rivers, adding to its strategic importance (8º 19' N, 9º 51' E). Lau, a Local Government Area with predominantly Hausa-Fulani inhabitants, borders several other local governments, including Ardo Kola, Jalingo, Yorro, and Zing, with its headquarters in the town of Lau (9º 12' N, 11º 16' E). Lastly, Mayo-Ranewo, known for its notable fish market, is situated 8 kilometers off the Jalingo-Wukari road along the banks of the River Benue, making it a hub for regional trade and commerce (Figure.1).

Figure 1. Map of study area showing Taraba State, River Benue and the three-sampling station (Lau, Mayo Ranewo, and Ibi). Image generated with Google Earth^{TM} mapping service.

2.2 Experimental design

The research spanned 18 months, from January 2020 to June 2021, focusing on the abundance and seasonal variations of phytoplankton communities in the River Benue. Monthly phytoplankton samples were collected throughout both dry and wet seasons. Simultaneously, water quality parameters were monitored at three sampling locations: Lau (Site A), Mayo-Ranewo (Site B), and Ibi (Site C), as depicted in the study area map in Fig. 1.

2.3 Phytoplankton diversity and abundance analysis

Phytoplankton samples were collected with one litter transparent plastic bottle by dipping the container bottle, sliding over the upper surface of water with its mouth against the water current to permit undisturbed passage of the water into the bottle (Tanimu, 2011). Samples were preserved with Lugol's solution and brought to the laboratory. Slides were prepared and observed under a binocular microscope (Optika B-290TB, Italy) with various magnifications. Taxonomic identification of plankton was carried out by using taxonomic keys (Emi and Andy, 2007; Edward and David, 2010; Steve *et al.,* 2013). The phytoplankton were counted from left top corner of the slide to the right corner by moving the slide horizontally.

2.4 Determination of physicochemical parameters

Physicochemical parameters, including temperature, pH, turbidity, electrical conductivity, total dissolved solids (TDS), dissolved oxygen (DO), biochemical oxygen demand (BOD), hardness, fluoride, and nitrate, were analysed. Water samples were collected across the seasons from three sampling stations. Parameters such as temperature, pH, turbidity, DO, electrical conductivity, and TDS were measured on-site using a Horiba water testing device (Horiba, model U-50, Kyoto, Japan). For nitrate, hardness, and BOD analysis, water samples were collected in bottles, placed in a cooler with ice, and transported to the laboratory at the Taraba State Water Supply Agency. The samples were prepared according to the standard procedures specified by the manufacturer of the analytical equipment (Wagtech Palintest Photometer model 7100).

3 Statistical analysis

The obtained data for physicochemical parameters were subjected to description statistical analysis to determine the mean-variance, standard deviation and graph (bar chart), one-way analysis of variance (ANOVA) to test their level of significance. To assess Phytoplankton abundance and diversity, several indices were used including simple percentage and Shannon Weiner's diversity index (H) as in Eyo and Paul, (2015), it was calculated by using the formula shown below;

Shannon-weiner diversity index (H) = $-\sum$ (Pi x ln Pi) S
Where; H is the Shannon diversity index
Pi is the fraction of the entire population made up of species
i is the estimation of the proportion as Pi=ni/N
S is numbers of species encountered
$\sum$ is sum from species 1 to species S
Ln is the natural log, which makes the terms of the summation negative.

Kerkhoff, (2010), states that typical values of Shannon Weiner index are generally between 1.5 and 3.5 in most ecological studies, and the index is rarely greater than 4. Evenness is an index that makes the *H* values comparable between communities by controlling the number of species found within the communities

$$E = \frac{H}{LnHmax}$$

Where;

H= Shannon Weiner value

Hmax= Total number of species

E can range from close to 0 or close to 1. When it is close to zero, it means all species are rare and just a few are abundant, close to 1 means the potential evenness between species (*Hmax*) is equal to that which was observed (*H*)

Xlstat was used to conduct the Principal Component Analysis (PCA) between the physico-chemical parameter of the river and the distribution of phytoplankton composition. PCA biplot was used to determine the relationship between the distribution and composition of phytoplankton and the environmental parameters of the river, the type of angles formed between the variables shows the correlation between them; an acute angle indicates positive correlation, an obtuse angle indicates negative correlation, while a right-angle indicates no correlation. The measured variables were summarized using an eigenvalue with an extraction rule >1 which was used to plot a graph on the screen plot.

4. Results

The distribution of phytoplankton in the River Benue varied significantly between the dry and wet seasons across the three sampling sites: Lau (Site A), Mayo-Ranewo (Site B), and Ibi (Site C). During the dry season (January–March 2020), Site A recorded phytoplankton counts of 284, 280, 424, totaling 988, indicating moderate abundance. In contrast, during the wet season (April 2020–June 2021), phytoplankton abundance increased, with counts at Site A rising to 395, 385, 748, with a total of 1,528 (Table 1).

The pie chart revealed that *Microcystis flos-aquae* (16.54%) and *Euglena gracilis* (15.84%) were the most dominant species, followed closely by *Spirogyra sp.* (13.38%). These species collectively contributed to nearly half of the total phytoplankton abundance, indicating their significant role in the ecosystem at Lau (Fig. 3). *Spirogyra sp*. exhibited a relatively stable trend, with peaks in November and March, indicating resilience to seasonal changes. *Euglena gracilis* had its highest abundance in January 2021, likely due to improved nutrient conditions. *Navicula cuspidate* showed moderate abundance throughout, reflecting adaptability to varying conditions (Fig. 4).

Table 1: phytoplankton distribution during both season in River Benue at Lau, Mayo-ranewo, and Ibi

Season	Dry season (Jan 2020-March. 2020)	Wet season (April 2020- June, 2021)
Site A	284	395
Site B	280	385
Site C	424	748
Total	988	1528

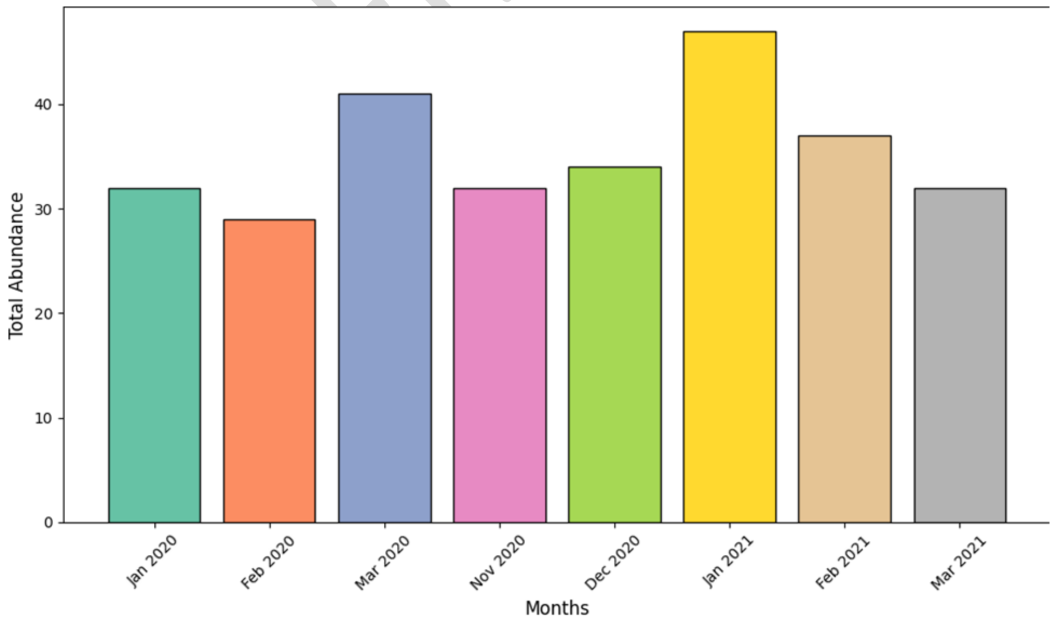


Figure 2: Total abundance per month and fluctuations of phytoplankton during dry season at Lau

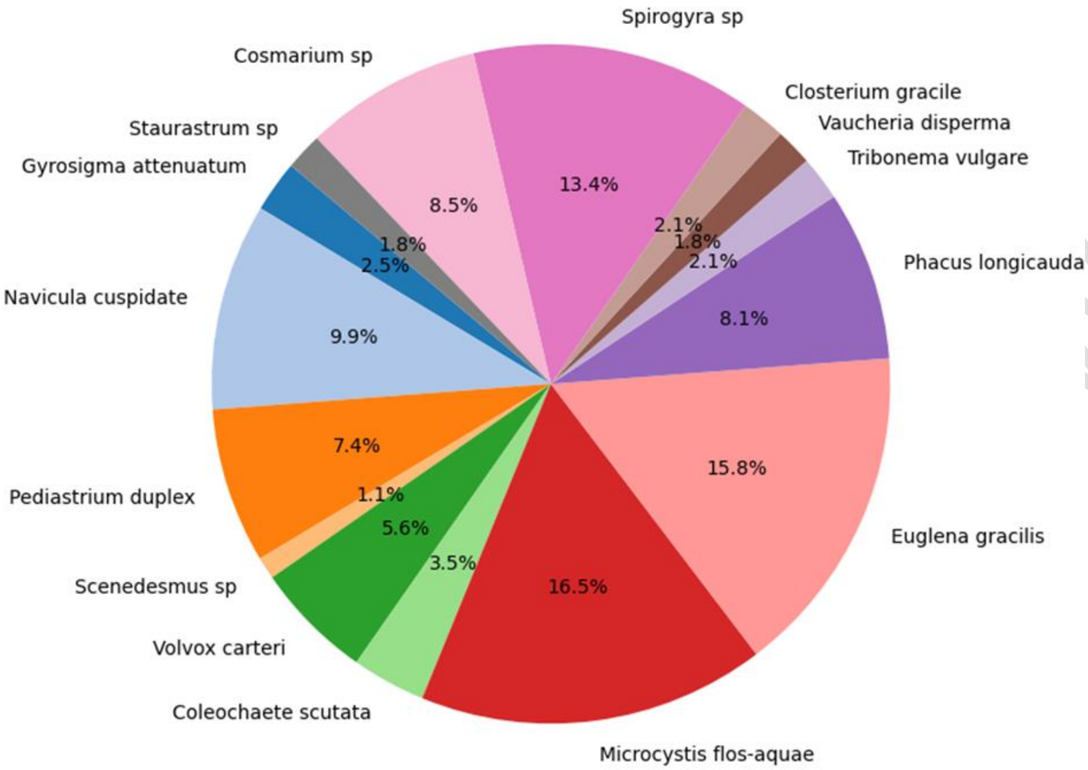


Figure 3: Percentage contribution of each phytoplankton species to the overall abundance during dry season at Lau

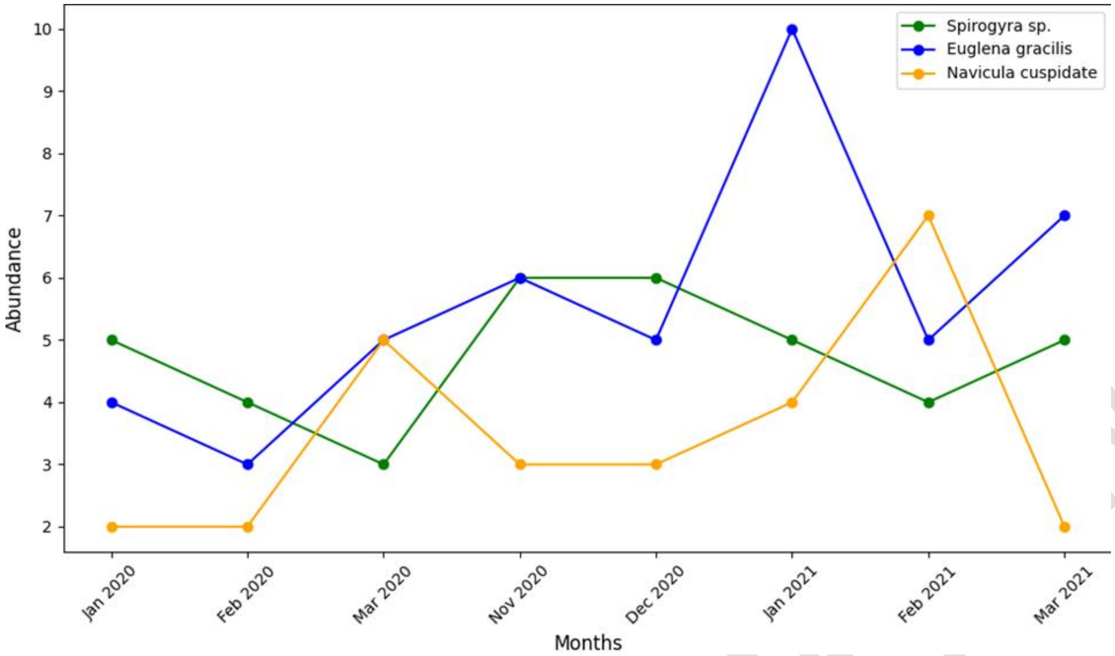


Figure 4: Seasonal trends for *Spirogyra sp.*, *Euglena gracilis*, and *Navicula cuspidate* during dry season at Lau.

Phytoplankton's abundance was highest in March 2020 (46 individuals) and lowest in January 2021 (28 individuals), indicating site-specific differences in phytoplankton dynamics compared to Site A (Fig. 5). Mayo-ranewo sampling site showed *Spirogyra sp*. (15%), *Euglena gracilis* (14.64%), and *Navicula cuspidate* (14.64%) as the key contributors (Fig. 6). Spirogyra sp. peaked sharply in March, suggesting favourable seasonal conditions at that time. *Euglena gracilis* had a consistent presence, with a slight peak in January 2021, aligning with seasonal nutrient availability. *Navicula cuspidate* followed a steady trend but was slightly less dominant compared to Site A (Fig. 7).

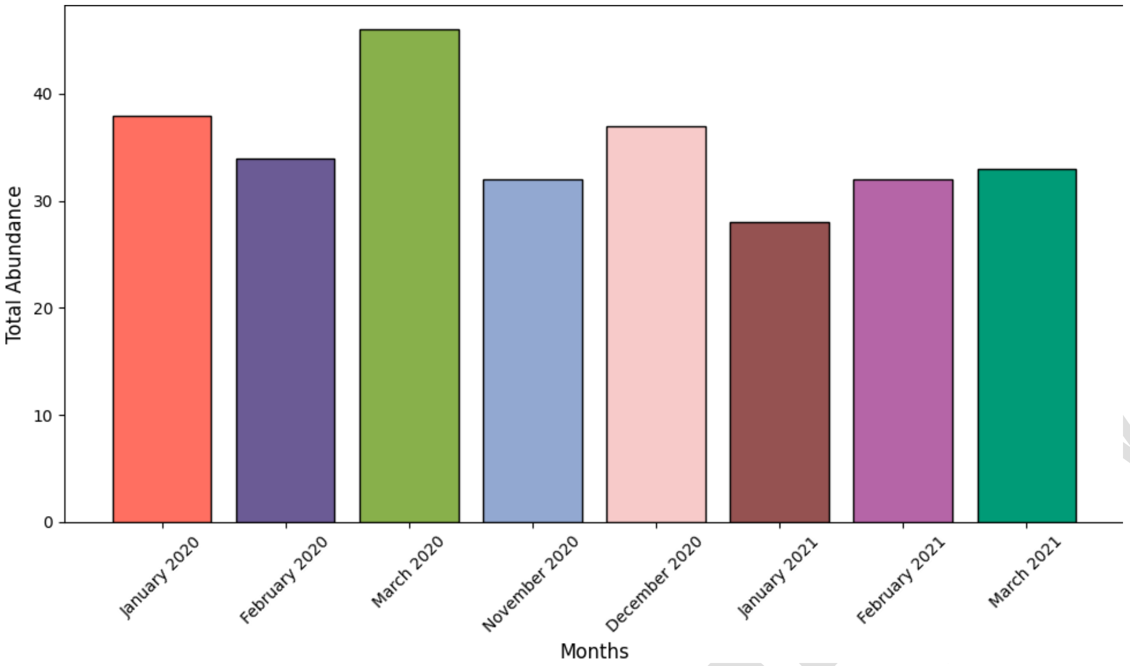


Figure 5: Total abundance per month and fluctuations of phytoplankton abundance in River Benue at Mayo-ranewo (B) across the study period

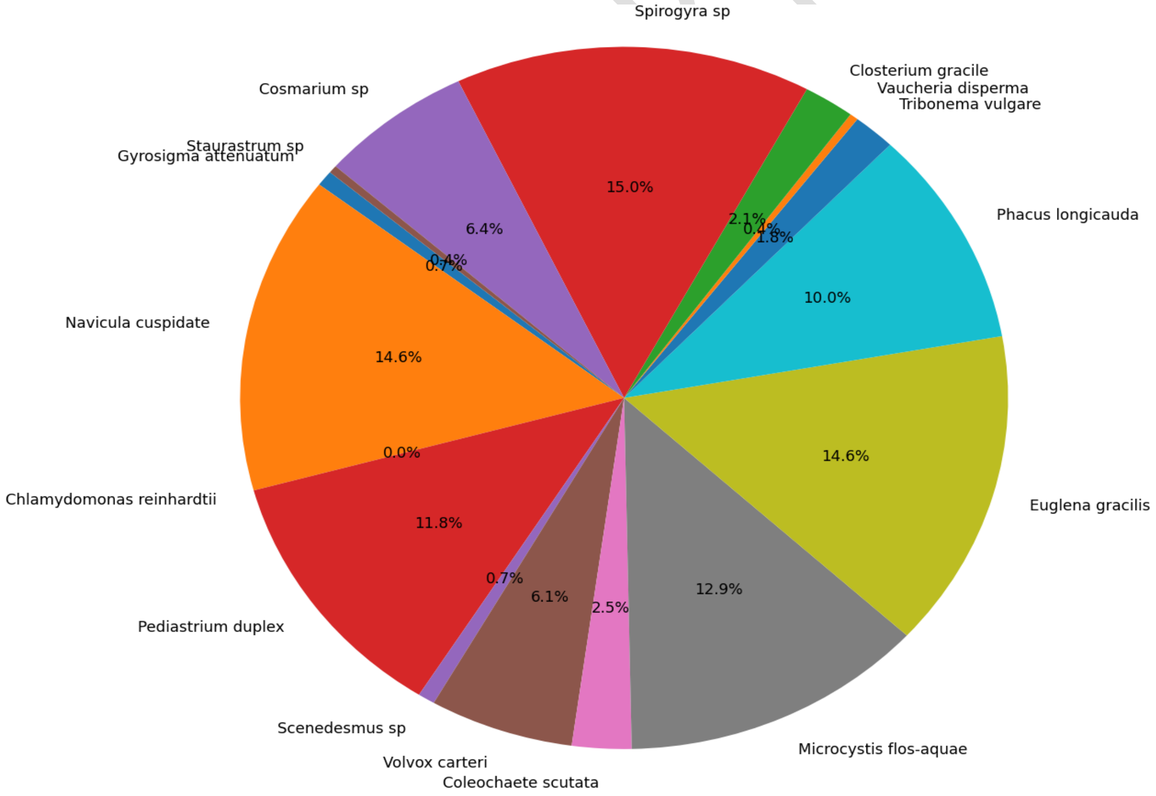


Figure 6: Percentage contribution of each phytoplankton group/species to the overall abundance in River Benue at Mayo-ranewo (B) across the study period.

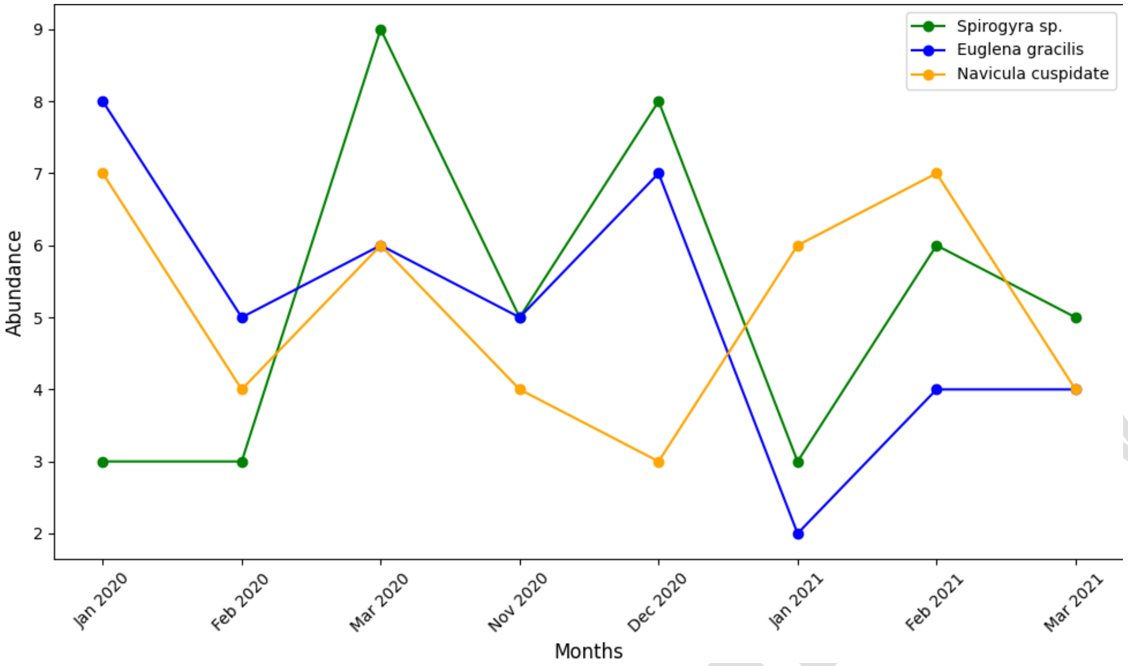


Figure 7: Seasonal trends of key species, *Spirogyra sp*., *Euglena gracilis*, and *Navicula cuspidate* in River Benue at Mayo-ranewo across the study period

Figure 8 shows monthly variations in the abundance of key phytoplankton species in Site C during the dry season. *Spirogyra sp* and *Cosmarium sp* dominate, with peaks in January 2020 and early 2021, respectively, while *Euglena gracilis* also contributes significantly. In contrast, *Navicula cuspidate* and *Microcystis flos-aquae* show moderate and steady trends. These patterns reflect seasonal influences on phytoplankton dynamics, driven by environmental factors.

The result illustrates the proportional abundance of phytoplankton species in Site C during the dry season. *Spirogyra sp* (18.6%) and *Cosmarium sp* (17.2%) are the most dominant species, followed by *Euglena gracilis* (15.1%) and *Microcystis flos-aquae* (13.4%). Other species contribute smaller proportions, with rare taxa like *Chlamydomonas reinhardtii* (<1%) having minimal impact. This distribution highlights the dominance of a few species while maintaining community diversity with contributions from less abundant species (Fig. 9)

Figure 10 illustrates the monthly abundance trends of key phytoplankton species in Site C during the dry season. *Spirogyra sp* and *Cosmarium sp* display the highest and most fluctuating abundances, with distinct peaks in January 2020 and early 2021. *Euglena gracilis* maintains relatively stable abundance, while *Navicula cuspidate* and *Microcystis flos-aquae* exhibit moderate and consistent trends.

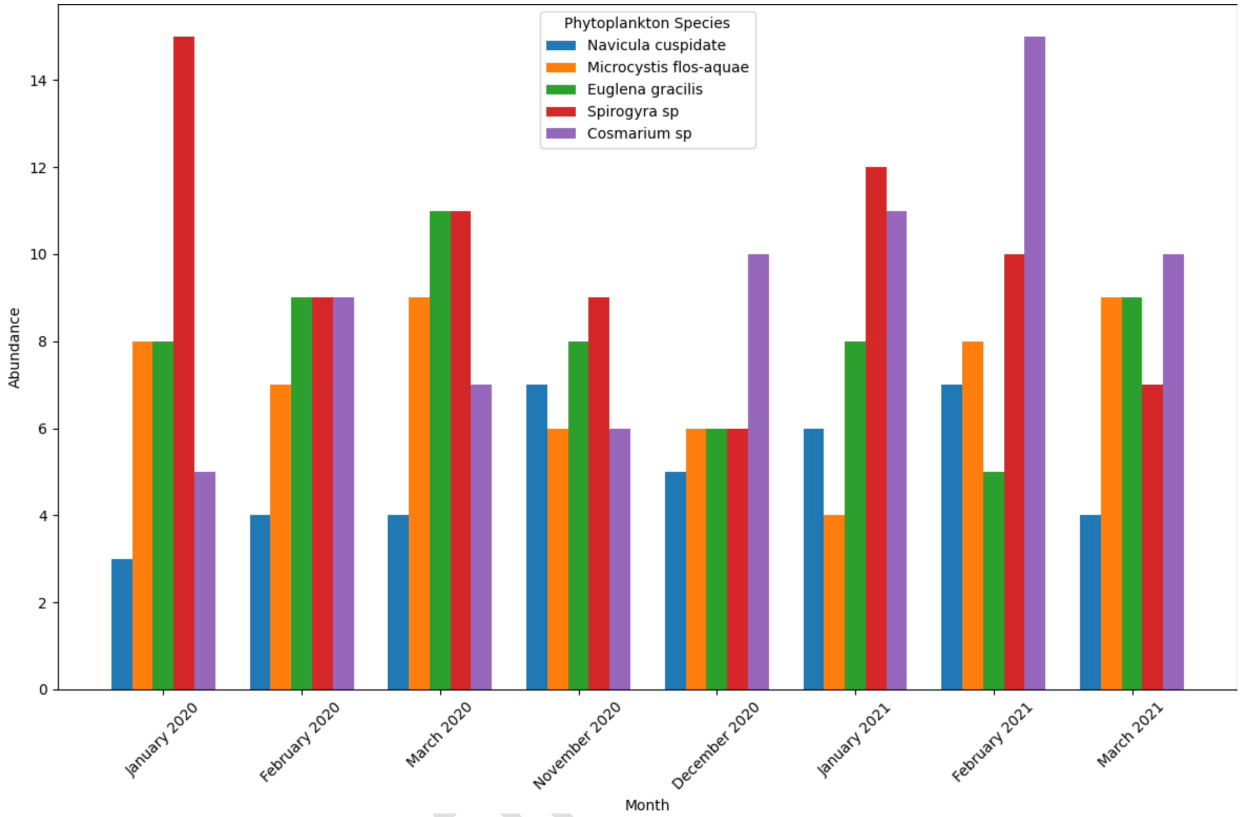


Figure 8: Monthly abundance of the key phytoplankton species during dry season in River Benue at Ibi

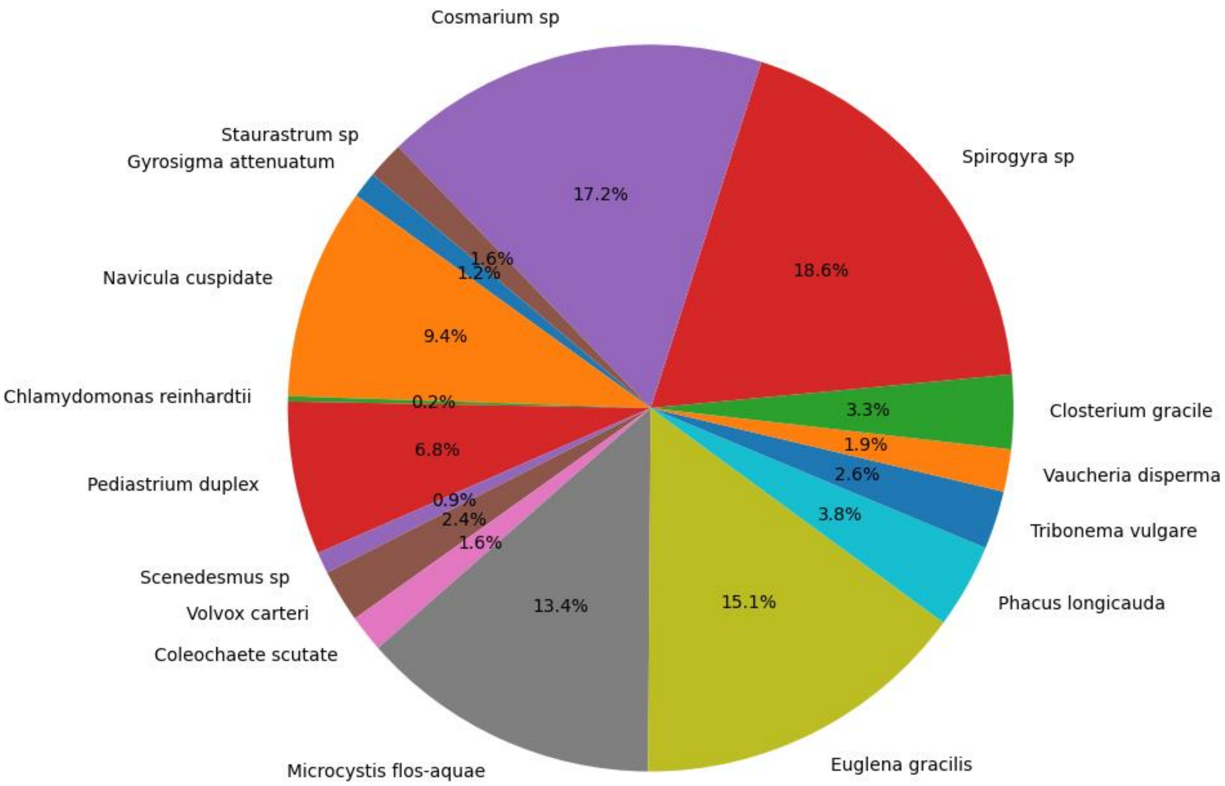


Figure 9: Percentage contribution of each phytoplankton group/species to the overall abundance in River Benue at Ibi across the study period.

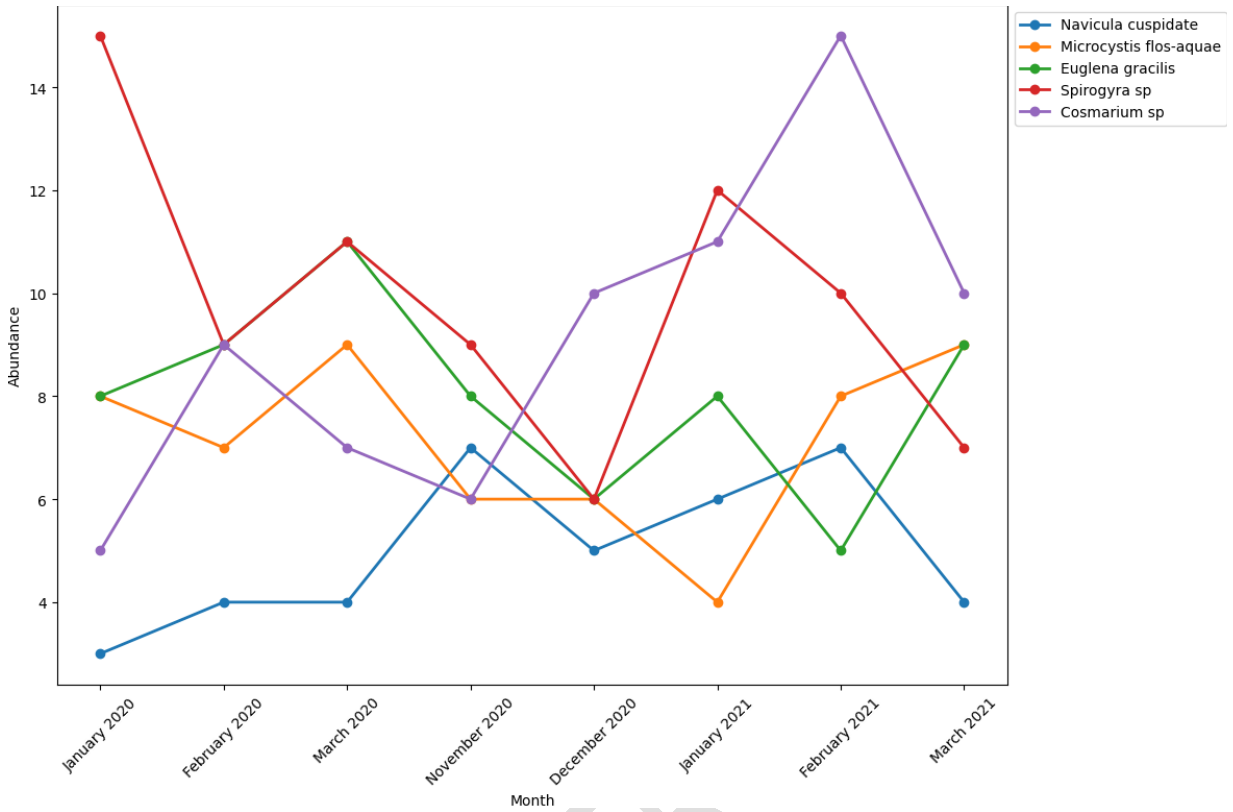


Figure 10: Seasonal trends of key species, *Spirogyra sp*., *Euglena gracilis*, *Navicula cuspidate*, *Cosmarium sp* and *Microcystis flos-aquae* in River Benue at Mayo-ranewo across the study period

Figure 11 shows monthly variations in the abundance of key phytoplankton species in Site A during the dry season. *Spirogyra sp* and *Cosmarium sp* dominate, with peaks in January 2020 and early 2021, respectively, while *Euglena gracilis* also contributes significantly. In contrast, *Navicula cuspidate* and *Microcystis flos-aquae* show moderate and steady trends. These patterns reflect seasonal influences on phytoplankton dynamics, driven by environmental factors.

The result illustrates the proportional abundance of phytoplankton species in Site A during the wet season. *Euglena gracilis* (14.4%) and *Microcystis flos-aquae* (13.4%) followed by and *Spirogyra sp* (12.2%) and *Cosmarium sp* (10.1%) are the most dominant species. Other species contribute smaller proportions, with rare taxa like *Chlamydomonas reinhardtii* (<1%) having minimal impact. This distribution highlights the dominance of a few species while maintaining community diversity with contributions from less abundant species (Fig. 12)

Figure 13 illustrates the monthly abundance trends of key phytoplankton species in Site A during the wet season. *Spirogyra sp* and *Microcystis flos-aquae* display the highest and most fluctuating abundances, with distinct peaks in May and August 2020 and May 2021. *Euglena gracilis* maintains relatively stable abundance, while *Navicula cuspidate* exhibit moderate and consistent trends.

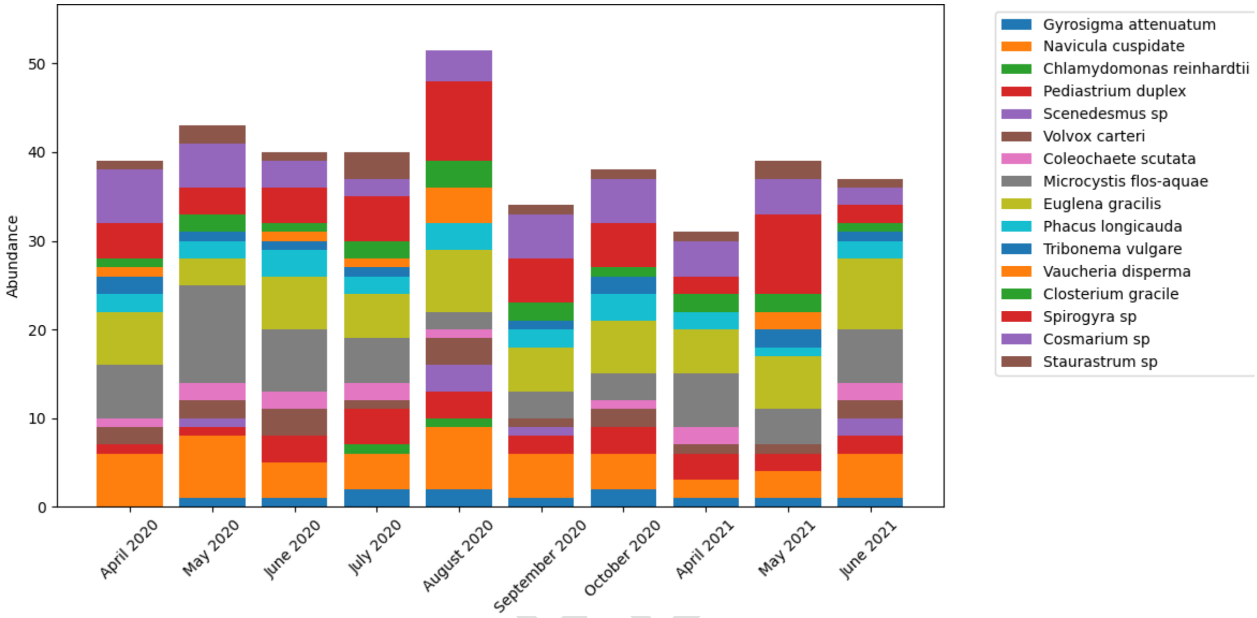


Figure 11: Monthly phytoplankton abundance for each species in Site A during the wet season.

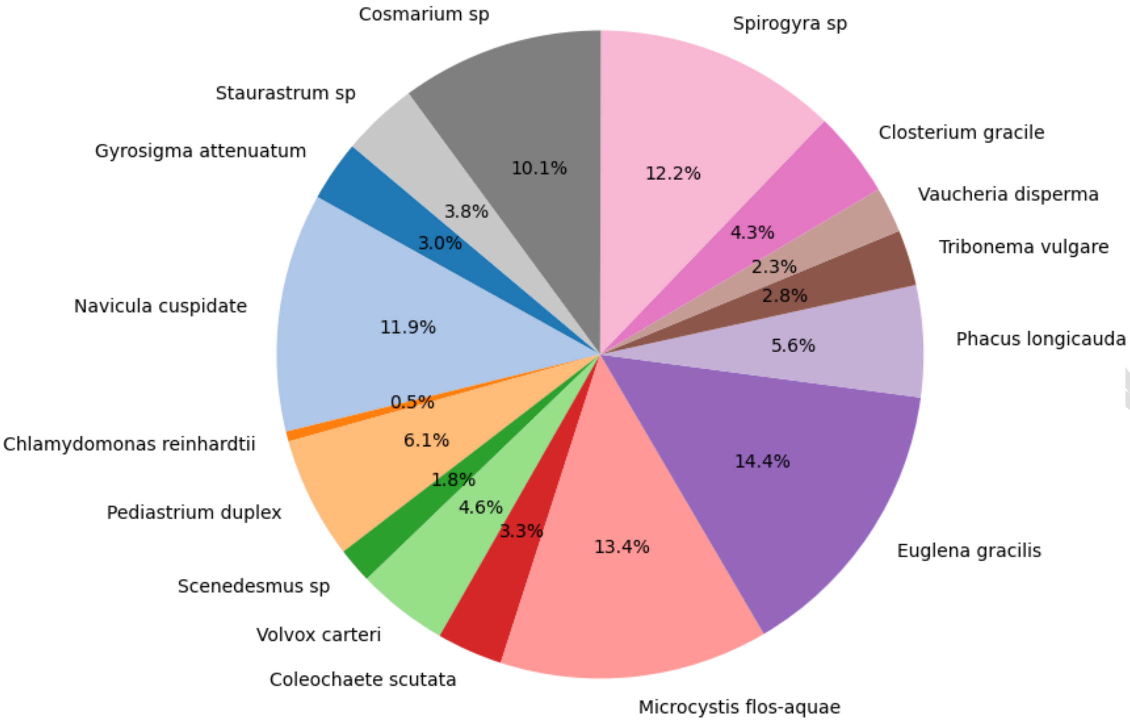
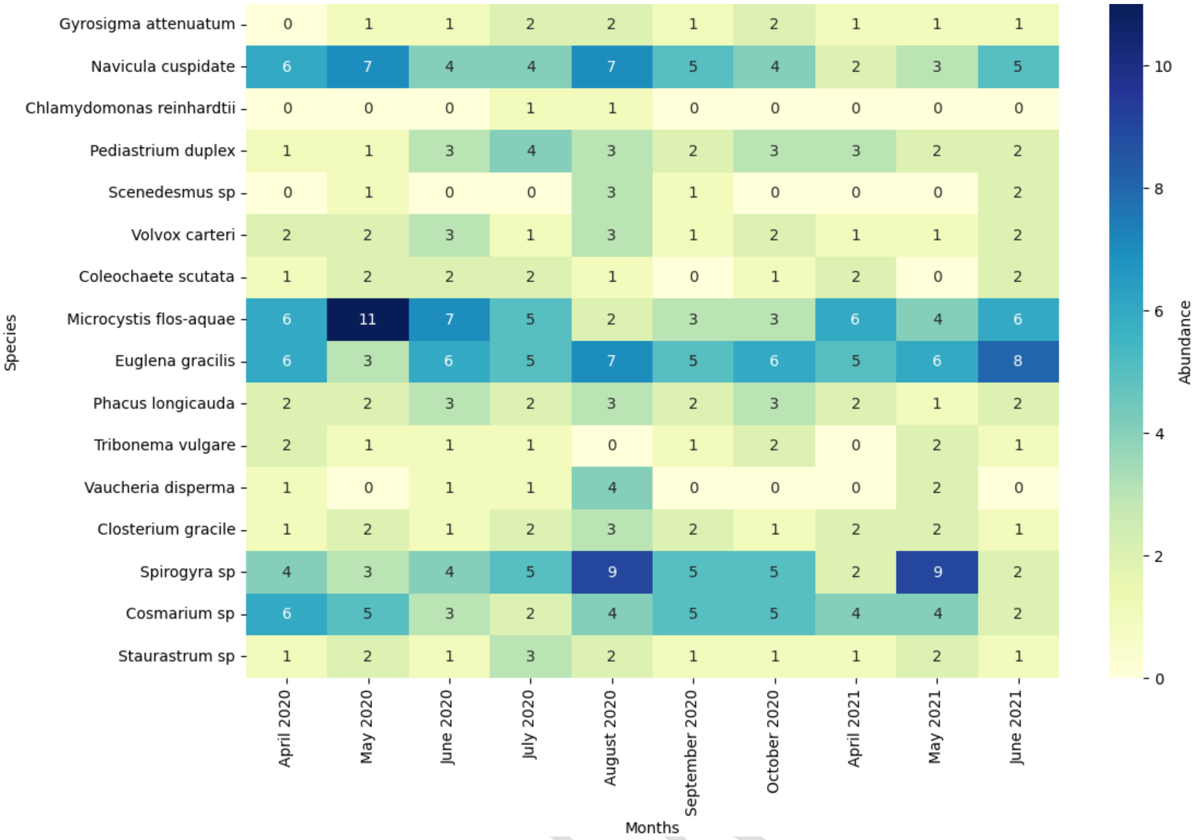


Figure 12: Relative abundance of different phytoplankton species based on their contribution to the total abundance



	April 2020	May 2020	June 2020	July 2020	August 2020	September 2020	October 2020	April 2021	May 2021	June 2021
Gyrosigma attenuatum	0	1	1	2	2	1	2	1	1	1
Navicula cuspidate	6	7	4	4	7	5	4	2	3	5
Chlamydomonas reinhardtii	0	0	0	1	1	0	0	0	0	0
Pediastrium duplex	1	1	3	4	3	2	3	3	2	2
Scenedesmus sp	0	1	0	0	3	1	0	0	0	2
Volvox carteri	2	2	3	1	3	1	2	1	1	2
Coleochaete scutata	1	2	2	2	1	0	1	2	0	2
Microcystis flos-aquae	6	11	7	5	2	3	3	6	4	6
Euglena gracilis	6	3	6	5	7	5	6	5	6	8
Phacus longicauda	2	2	3	2	3	2	3	2	1	2
Tribonema vulgare	2	1	1	1	0	1	2	0	2	1
Vaucheria disperma	1	0	1	1	4	0	0	0	2	0
Closterium gracile	1	2	1	2	3	2	1	2	2	1
Spirogyra sp	4	3	4	5	9	5	5	2	9	2
Cosmarium sp	6	5	3	2	4	5	5	4	4	2
Staurastrum sp	1	2	1	3	2	1	1	1	2	1

Figure 13: Abundance patterns of each phytoplankton species across months using a colour gradient.

Figure 14 shows the total abundance of phytoplankton species observed in Site B during the wet season. Each bar represents the cumulative count of a species recorded across all months. *Navicula cuspidate* is the most abundant species, with the highest bar indicating its dominance. *Spirogyra sp, Euglena gracilis*, and *Pediastrium duplex* also show significant abundances, ranking among the top contributors. Species like *Chlamydomonas reinhardtii, Vaucheria disperma,* and *Staurastrum sp* are the least abundant, with minimal contributions.

The pie chart (Fig 15) illustrates the percentage composition of phytoplankton species based on their total abundance during the wet season in Site B. *Navicula cuspidate* contributes the largest proportion at 14.0%, making it the most dominant species. Other significant contributors include *Spirogyra sp* (13.5%), *Euglena gracilis* (12.5%), and *Pediastrium duplex* (12.2%), which together account for a substantial share of the phytoplankton population. Species like *Chlamydomonas* *reinhardtii* (0.3%), *Vaucheria disperma* (0.8%), and *Staurastrum sp* (0.8%) make up the smallest proportions, highlighting their relatively low abundance.

Figure 16 shows the monthly abundance of phytoplankton species at Site B during the wet season from April 2020 to June 2021. The intensity of the colour indicates abundance, with darker blue representing higher counts and lighter yellow representing lower counts. *Navicula cuspidate, Spirogyra sp* and *Euglena gracilis* show high abundances across multiple months, particularly in May and June 2020. Some species, like *Chlamydomonas reinhardtii* and *Staurastrum sp,* have minimal abundance throughout the period. Seasonal fluctuations are evident, with peaks in specific months (e.g., *Euglena gracilis* peaks in August 2020).

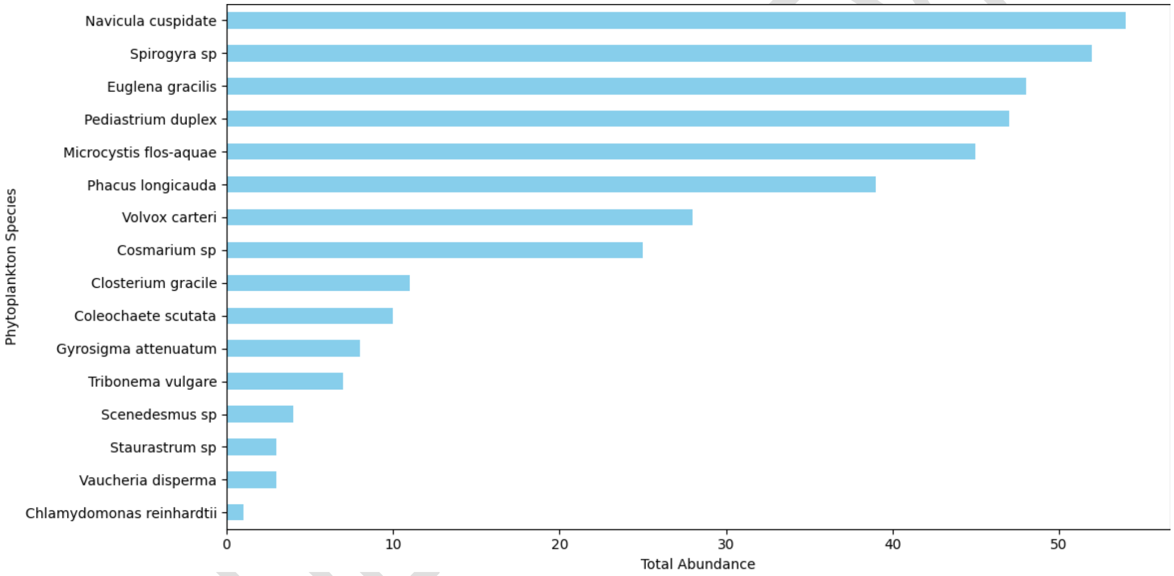


Figure 14: Total abundance of phytoplankton species observed in Site B during the wet season.

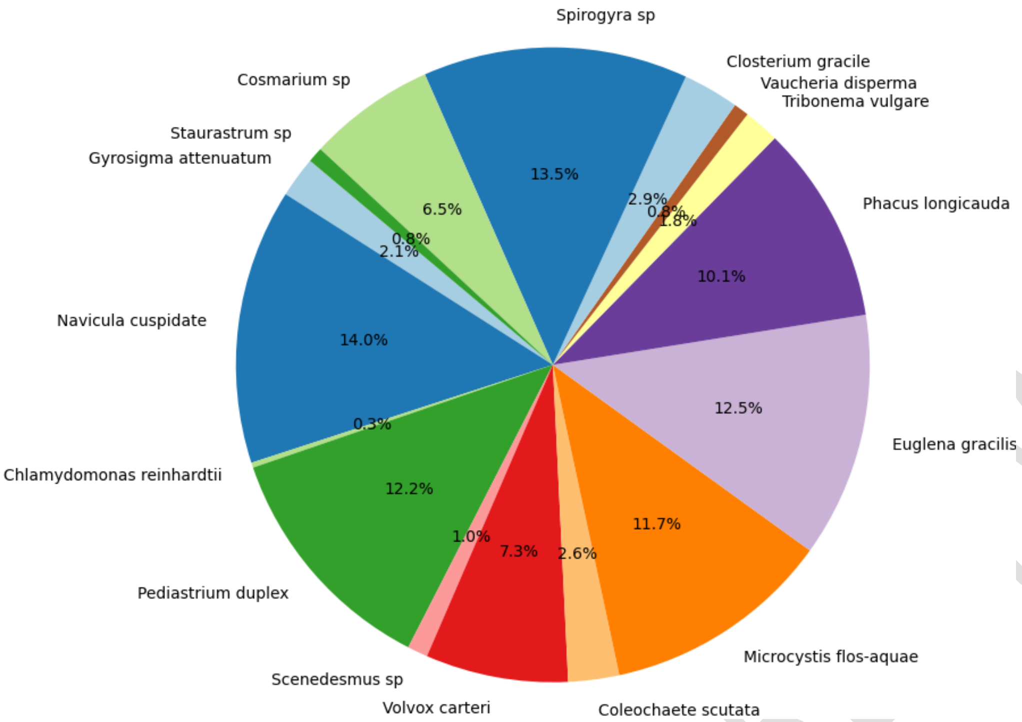


Figure 15: Percentage composition of phytoplankton species based on their total abundance during the wet season in Site B.

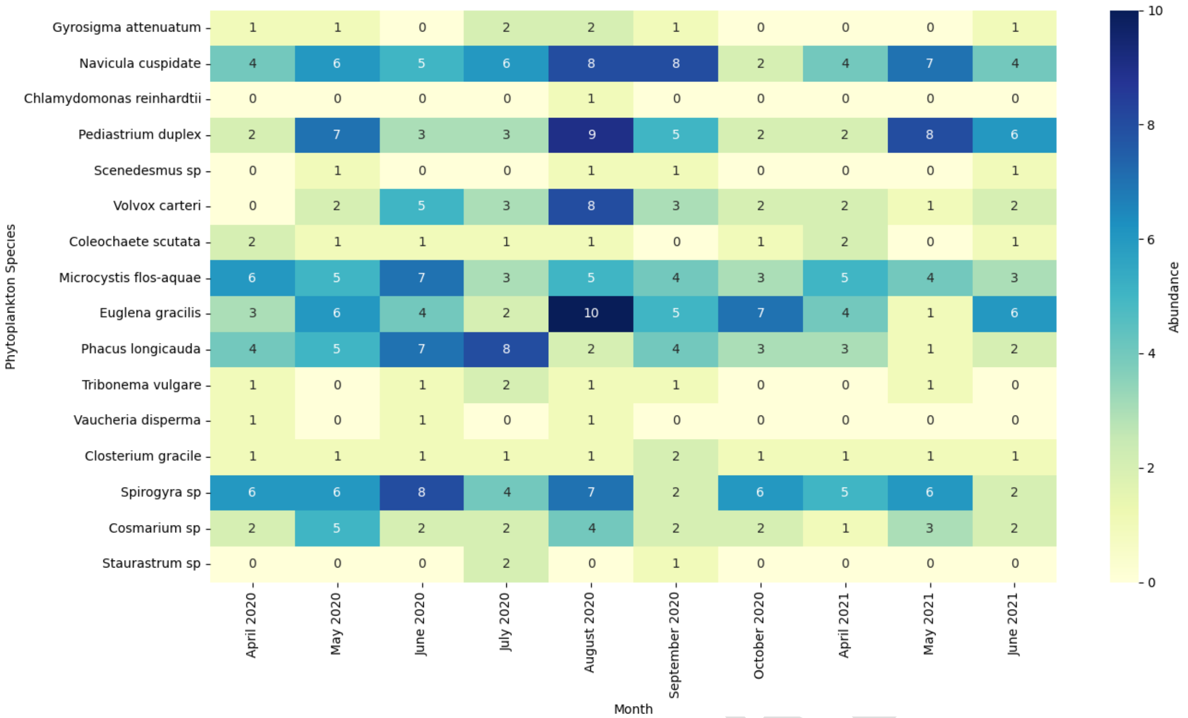


Figure 16: Monthly abundance of phytoplankton species at Site B during the wet season from April 2020 to June 2021.

Figure 17 highlights phytoplankton abundance, with *Spirogyra sp* dominating, followed by *Microcystis flos-aquae* and *Euglena gracilis*, while species like *Gyrosigma attenuatum* and *Chlamydomonas reinhardtii* are minimal.

Figure 18 shows *Spirogyra sp* as the most abundant (25.4%), followed by *Microcystis flos-aquae* (19.5%) and *Euglena gracilis* (15.4%). Species like *Cosmarium sp* (12.0%) and *Closterium gracile* (5.7%) contribute modestly, with others being negligible.

Figure 19 reveals monthly abundance trends, with *Spirogyra sp* and *Microcystis flos-aquae* peaking, particularly *Spirogyra sp* in August 2020 and May 2021. Minimal contributors include *Chlamydomonas reinhardtii* and *Scenedesmus sp*. The colour gradient emphasizes abundance dynamics over time.

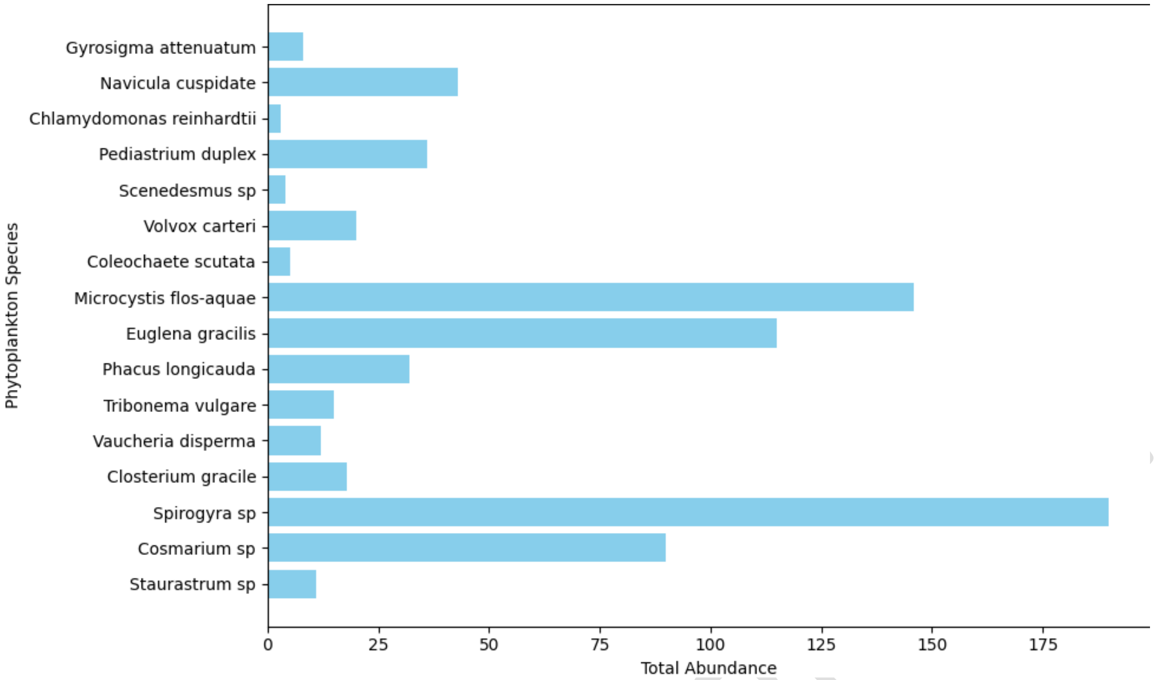


Figure 17: Total abundance of phytoplankton species observed in Site C during the wet season.

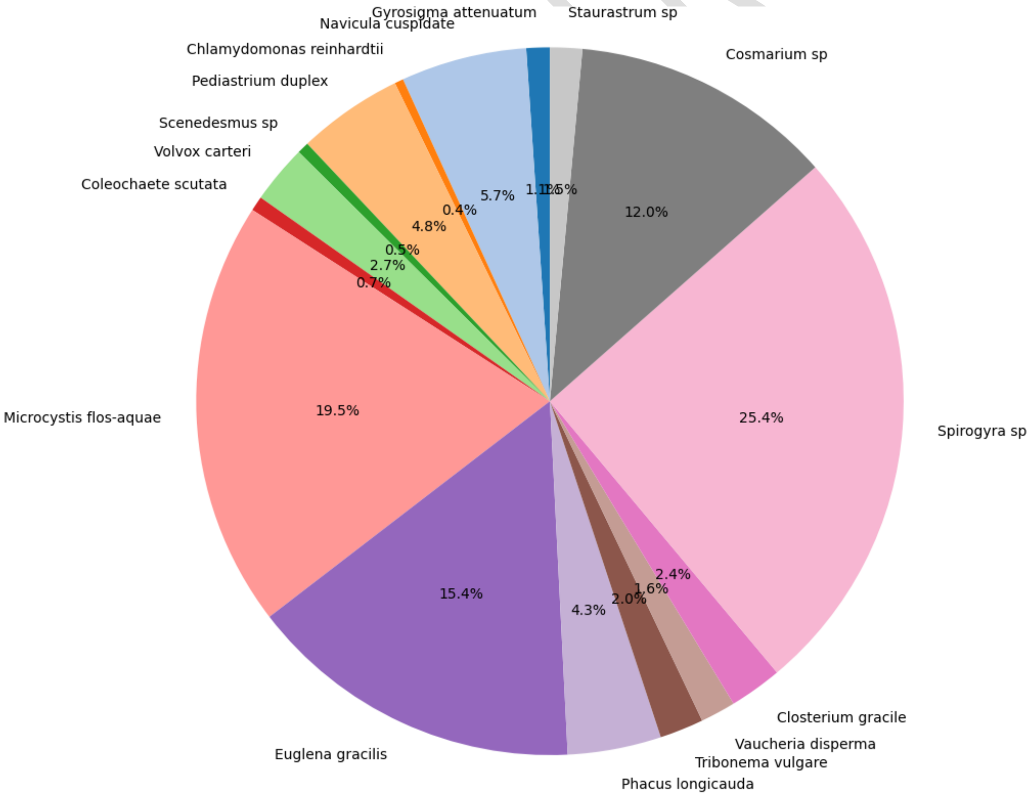
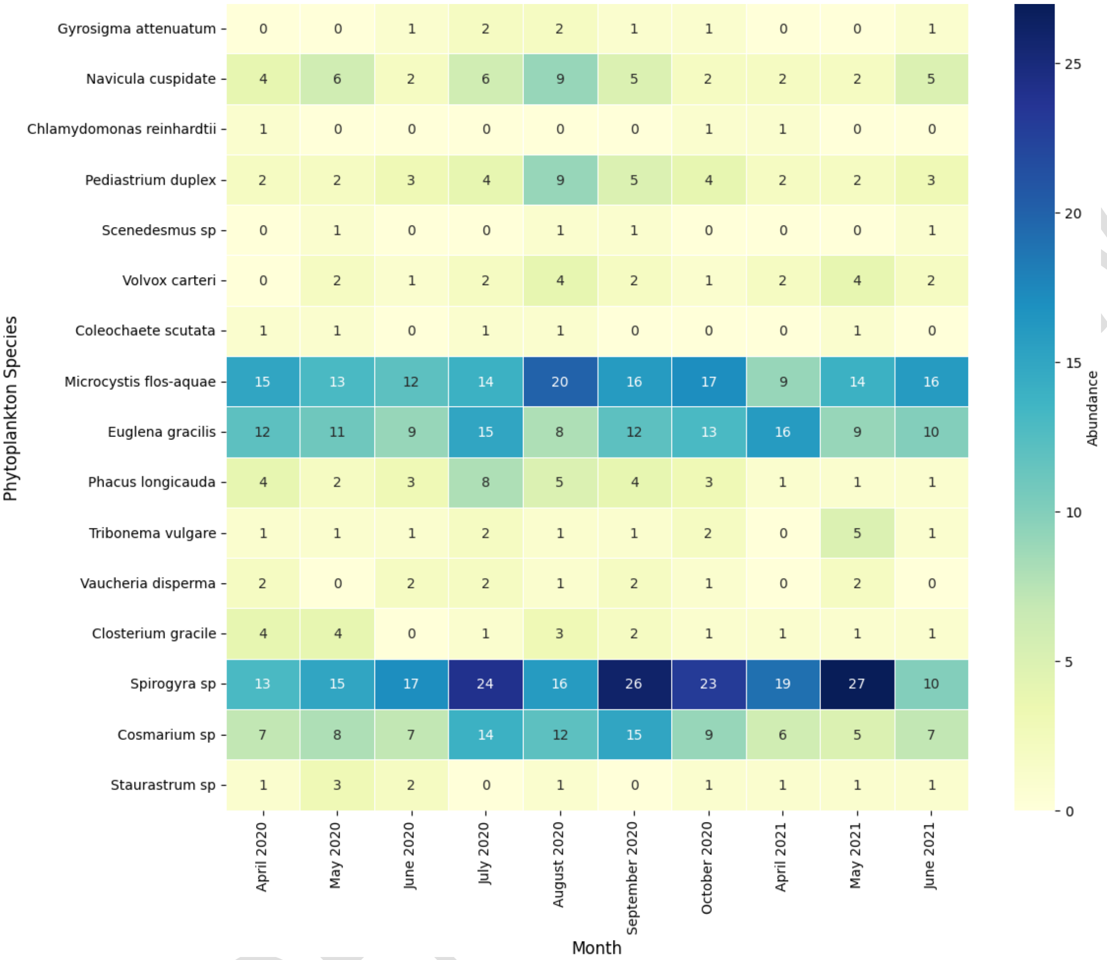


Figure 18: Percentage composition of phytoplankton species based on their total abundance during the wet season in Site C.



Phytoplankton Species	April 2020	May 2020	June 2020	July 2020	August 2020	September 2020	October 2020	April 2021	May 2021	June 2021
Gyrosigma attenuatum	0	0	1	2	2	1	1	0	0	1
Navicula cuspidate	4	6	2	6	9	5	2	2	2	5
Chlamydomonas reinhardtii	1	0	0	0	0	0	1	1	0	0
Pediastrium duplex	2	2	3	4	9	5	4	2	2	3
Scenedesmus sp	0	1	0	0	1	1	0	0	0	1
Volvox carteri	0	2	1	2	4	2	1	2	4	2
Coleochaete scutata	1	1	0	1	1	0	0	0	1	0
Microcystis flos-aquae	15	13	12	14	20	16	17	9	14	16
Euglena gracilis	12	11	9	15	8	12	13	16	9	10
Phacus longicauda	4	2	3	8	5	4	3	1	1	1
Tribonema vulgare	1	1	1	2	1	1	2	0	5	1
Vaucheria disperma	2	0	2	2	1	2	1	0	2	0
Closterium gracile	4	4	0	1	3	2	1	1	1	1
Spirogyra sp	13	15	17	24	16	26	23	19	27	10
Cosmarium sp	7	8	7	14	12	15	9	6	5	7
Staurastrum sp	1	3	2	0	1	0	1	1	1	1

Figure 19: Monthly abundance of phytoplankton species at Site C during the wet season from April 2020 to June 2021.

4.3 Phytoplankton dependence on environmental parameters

The composition and distribution of the planktons by classes in River Benue, showed that phytoplankton's composition, Site C had the highest with 748 (21.31%) during the wet season, while, Site B during the Wet season period recorded the lowest with 385 (10.97%). The distributions are displayed in Table 2.

Table 2: Phytoplankton Composition by class based on season sites in lower River Benue

Sites	Bacil	Chloro	Cyano	Eugleno	Xantho	Zygnema	Total	(%)
Dry season								
Site A	35	35	47	82	129	293	621	17.69
Site B	43	43	36	79	115	273	589	16.78
Site C	45	45	57	102	159	363	771	21.97
Wet season								
Site A	59	64	53	79	20	120	395	11.25
Site B	62	90	45	87	10	91	385	10.97
Site C	51	68	146	147	27	309	748	21.31
Total	295	345	384	576	460	1449	3509	

Keys:

Bacil: Bacillariophyceae

Chloro: Chlorophyceae

Cyano: Cyanophyceae

Eugleno: Euglenophyceae

Xantho: Xanthophyceae

Zygnema: Zygnematophyceae

The PCA biplot of phytoplankton in the dry season period showed that temperature is negatively correlated with Turbidity and Nitrate. BOD has a significant negative correlation with Fluoride and Nitrate. Conductivity is strongly negatively correlated with Nitrate and Fluoride, but Hardness shows a strong positive correlation with Fluoride and Nitrate. Turbidity has a strong positive correlation with Hardness and Nitrate. TDS is positively correlated with Conductivity and pH. DO shows moderate positive correlations with Hardness and *Euglenophyceae, Chlorophyceae* has a negative correlation with *Cyanophyceae* and *Bacillariophyceae* (Fig.20).

The analysis of the PCA biplot of phytoplankton in the wet season period showed that Total Dissolved Solids (TDS) has strong positive correlations with: BOD, pH, Hardness, and conductivity. Conductivity also has a strong positive correlation with BOD and Hardness. pH shows a strong correlation with BOD and Hardness. *Chlorophyceae* and *Cyanophyceae* are positively correlated pH and BOD. DO (Dissolved Oxygen) has a strong negative correlation with: Temperature and Nitrate. BOD is negatively correlated with Nitrate. Fluoride is negatively correlated with Nitrate. *Cyanophyceae* and *Chlorophyceae* show varying degrees of correlation, while *Euglenophyceae* and *Xanthophyceae* have lower correlations. Temperature is negatively correlated with DO and positively with TDS. Turbidity shows weak correlations overall, but is negatively correlated with *Cyanophycean*. BOD is positively correlated with TDS, pH, and hardness, while negatively correlated with nitrate levels (Fig. 21).

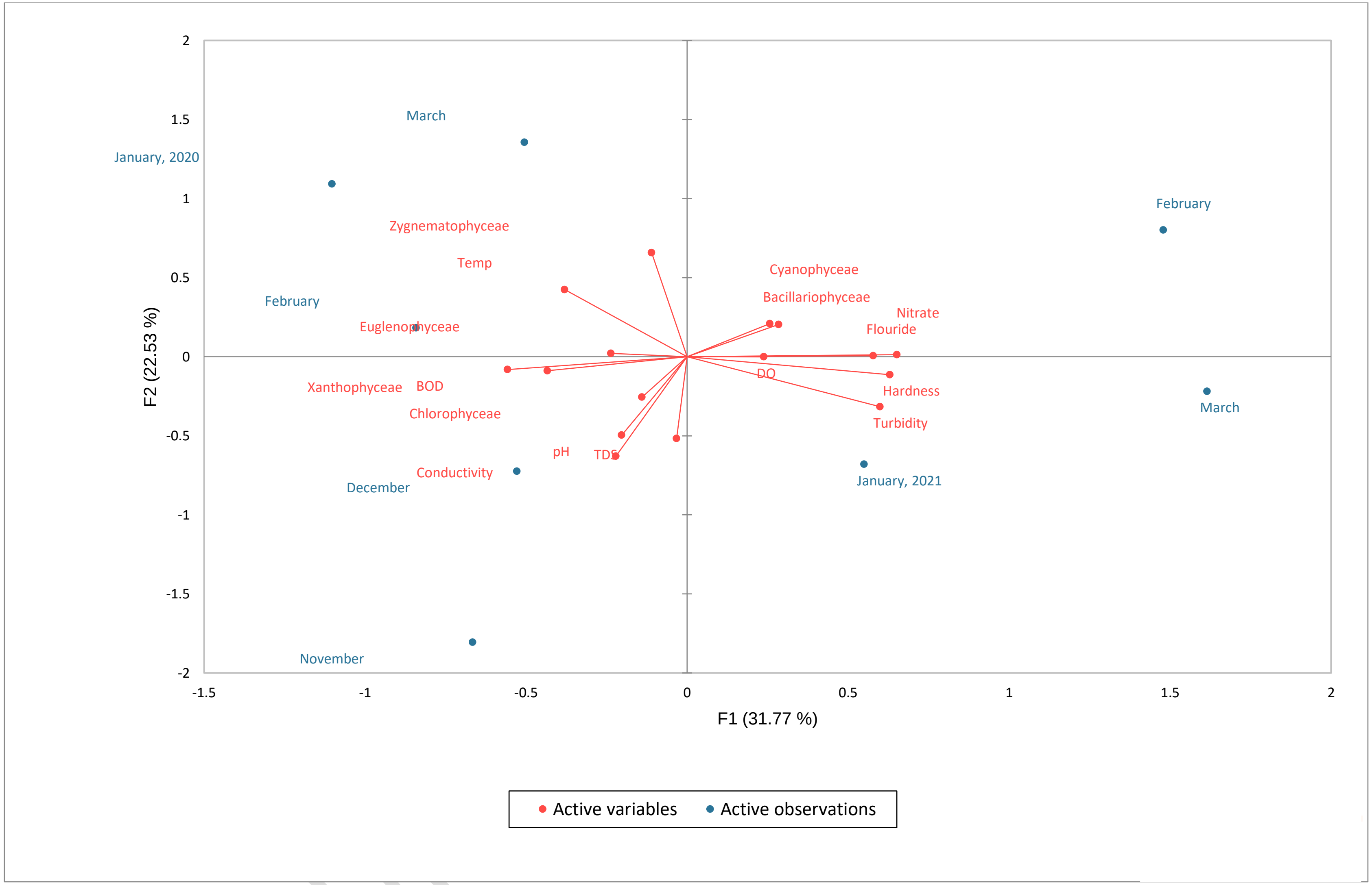


Figure 20: Biplot of phytoplankton and environmental parameters during dry season in River Benue

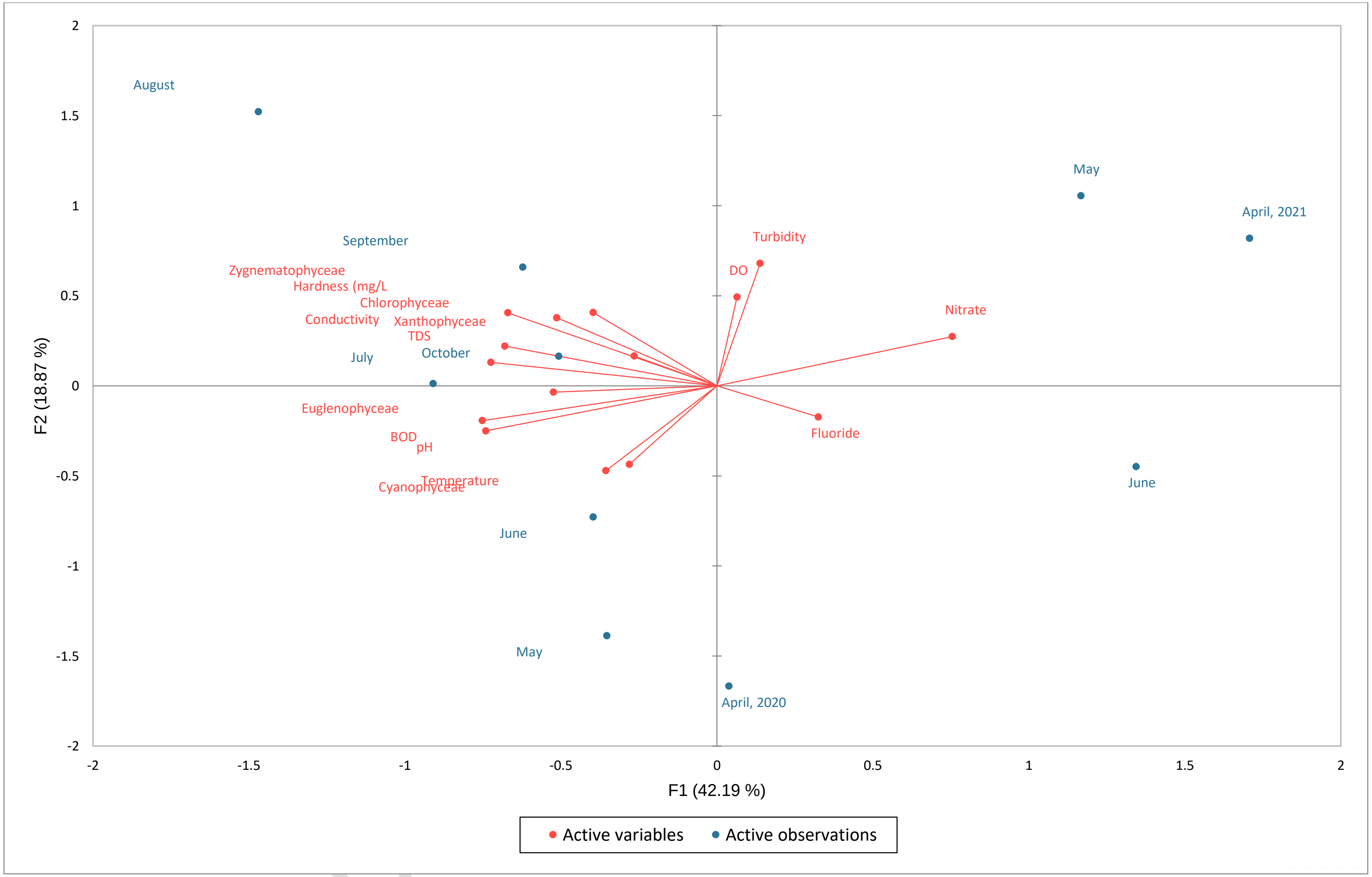


Figure 21: Biplot of phytoplankton and environmental parameters during wet season in River Benue

5. Discussion

5.1 Composition and distribution of phytoplankton

The composition and distribution of phytoplankton observed in this study differed significantly from previous findings. For instance, Onwudiwe et al. (2018) documented 58 individuals across four classes and nine species in Onah Lake, while Olele (2009) reported only 10 species in the same water body. In contrast, Adeyemi et al. (2008) identified 1,302 phytoplankton species belonging to four classes *Chlorophyta*, *Bacillariophyta*, *Cryptophyta*, and *Euglenophyta* in Gbedikere Lake, Bassa, Kogi State, Nigeria. Such differences could stem from variations in sampling duration, as extended sampling periods generally yield more comprehensive datasets.

A comparison of phytoplankton families in this study with earlier reports reveals further discrepancies. Oriakpono and Gabriel (2020) identified Bacillariophyceae as the dominant family with approximately 20 species, a trend also observed in studies of the Niger Delta rivers and creeks by Yakubu et al. (2020), Emmanuel and Onyema (2007), Davies et al. (2009), and Ogamba et al. (2015). Yakubu et al. (2020) recorded 17 species in the River Nun, and 20 and 34 species in the Orashi and Nkisa Rivers, respectively, while Erondu and Chinda (1991) identified 27 species in the New Calabar River. The predominance of Bacillariophyceae is thought to reflect the adaptive capacity of these species to develop robust self-sustaining mechanisms for growth and reproduction. Phytoplankton distribution is generally influenced by environmental factors such as water temperature, current velocity, nutrient availability, and light penetration (Okoseimiema et al., 2020).

Oriakpono and Gabriel (2020) reported higher phytoplankton populations in Station 3, contrasting with the findings of this study. They attributed this to anthropogenic activities, including waste disposal and faecal discharges, which increase nitrogen and other nutrients conducive to phytoplankton growth. Such observations align with Okoseimiema et al. (2020), who noted that local nutrient concentrations and temporal variations can significantly alter species composition at specific spatial locations.

The class composition and distribution of phytoplankton in this study differed significantly from previous reports. Onwudiwe et al. (2019) observed Chlorophyta as the most dominant class, accounting for 77.74% of the phytoplankton population, followed by Bacillariophyta (18.81%), with Cryptophyta and Euglenophyta contributing 3% each. In contrast, Adesalu (2010) recorded 55 species from Kainji Lake spanning four classes: Bacillariophyta, Cryptophyta, Euglenophyta, and Cyanophyta. Similarly, Offem et al. (2011) reported 34 species across four families in Ikwori Lake, while Abubakar and Yakasai (2013) identified 25 species from Ngulu Lake, comprising Chlorophyta, Cyanophyta, Bacillariophyta, and Dinophyta. These variations can be attributed to differences in sampling locality, weather conditions, time of day, sampling duration, and water parameters, as highlighted by Mahar (2003) and Abubakar (2009).

Phytoplankton population dynamics are influenced by environmental factors, including nutrient levels and predator populations, as noted by Ezra and Nwankwo (2001) in Gubi Lake. The current study corroborates their findings, observing higher phytoplankton densities during periods of intense sunlight (November 2020 and January 2021), consistent with the effects of high temperatures on photosynthetic activity reported by Ikenweiwe (2005) and Offem et al. (2011). The National Institute of Freshwater Fisheries Research (NIFFR, 1999) and Ikenweiwe and Otubusin (2005) similarly associated increased species diversity with elevated water temperatures. In terms of total phytoplankton abundance, this study aligns with reports by Ogbuagu and Ayoade (2012), Ekweozor (2016), and Ashiru et al. (2017), who observed higher phytoplankton populations compared to zooplankton in freshwater systems. These findings highlight the ecological significance of phytoplankton as primary producers, contributing to the aquatic food web and supporting fish production, as suggested by Boyd and Lichktoppler (1979).

Contrasting species dominance was observed among studies. For example, Onwudiwe et al. (2019) and Olele (2009) reported Closterium as the dominant species, whereas the present study recorded Chlorophyceae as the predominant group, a trend typical in African waters according to Kadiri (2011) and Abubakar et al. (2006). Ezekiel et al. (2011) noted

Bacillariophyceae (41.9%) as the dominant group in the Sombreiro River, followed by Chlorophyceae (32.6%), likely reflecting differences between lake and river ecosystems.

Seasonal factors, such as water mixing and flood patterns, also influence phytoplankton production. Karlman (1982) emphasized that variations in water turbidity and optical characteristics during seasonal mixing can affect phytoplankton growth. Viviane et al. (2012) similarly observed differences in phytoplankton composition across five major groups *Chlorophyceae, Cyanophyceae, Bacillariophyceae, Chrysophyceae*, and *Euglenophyceae* in tropical lakes. However, their recorded bimodal frequency during winter (Dec–Feb) differs from the present study, further underscoring the impact of local conditions on phytoplankton distribution.

5.2 Dynamism of environmental parameters with plankton

The PCA biplot indicates that Temperature from the study negatively correlate with both turbidity and nitrate during the dry season supports existing research on the influence of environmental factors on aquatic ecosystems. The observation that higher temperatures reduce turbidity and nitrate levels may be linked to increased water stratification or nutrient uptake by phytoplankton, which aligns with Ikomi & Adebisi (2003), who noted how seasonal changes in water temperature impact nutrient levels and fish distribution in Nigerian rivers. Seasonal stratification can limit nutrient mixing, thereby affecting the availability of essential nutrients for aquatic life.

The negatively significant correlation between Biological Oxygen Demand (BOD) and both fluoride and nitrate echo similar trends observed by Atobatele *et al.* (2020), who found that pollutants, particularly those associated with agricultural runoff, can disrupt organic matter decomposition processes. High fluoride and nitrate concentrations often result from industrial and agricultural activities, which could impede the breakdown of organic material in water, reducing BOD rates and altering the ecosystem's nutrient cycling. These findings are critical in managing water quality for both human use and ecosystem health, particularly in urbanized or industrial areas.

From the study conductivity is negatively correlated with both nitrate and fluoride could reflect the impact of salinity or dissolved ion concentrations on nutrient cycling, a relationship previously observed in studies such as Ogbeibu & Oribhabor (2002). Conductivity often increases with salinity or the presence of dissolved ions, which can alter nutrient availability in aquatic systems, potentially affecting the distribution and abundance of aquatic organisms. This aligns with Ikomi & Adebisi (2003), who also found that increased ion concentration influenced fish and other aquatic species distribution patterns

The study's positive correlation between water hardness, fluoride, and nitrate suggests that higher concentrations of calcium and magnesium are associated with elevated nutrient levels. This aligns with Adebisi's (1981) findings, which linked water hardness to nutrient enrichment in Nigerian rivers. Nutrient-rich, hard waters can enhance primary production, potentially increasing phytoplankton abundance. However, excessive nutrient levels may lead to eutrophication, posing risks to aquatic ecosystems. These findings highlight the need to monitor water hardness as a critical component of effective water quality management strategies.

The correlations observed in the study between *Euglenophyceae* and Dissolved Oxygen (DO), as well as the competitive interactions among *Chlorophyceae, Cyanophyceae*, and Bacillariophyceae, resonate with the phytoplankton dynamics discussed in Adeleke *et al.* (2020) and Ogbeibu & Oribhabor (2002). These studies highlight how environmental conditions, including nutrient availability and temperature, shape phytoplankton communities in Nigerian freshwater systems. Competition among different phytoplankton groups often intensifies under varying seasonal conditions, with nutrient fluctuations favouring different species at different times.

The negative correlation between DO and both temperature and nitrate in the study indicates potential hypoxic conditions during the wet season, a finding that aligns with studies like Ikomi & Adebisi (2003). Hypoxia poses a significant risk to aquatic life, especially fish and zooplankton communities, which depend on stable oxygen levels for survival. Monitoring DO and nutrient levels is therefore crucial for managing the ecological health of Nigerian river systems.

The strong positive correlations between Total Dissolved Solids (TDS), BOD, pH, Hardness, and Conductivity during the wet season reflect the influence of runoff and increased organic matter input into the water. Studies such as Adebisi (1981) and Ogbeibu & Oribhabor (2002) similarly reported that the wet season in Nigerian rivers is often characterized by higher nutrient loads and organic matter, driven by agricultural runoff and increased water flow. This influx of organic and inorganic matter during the wet season can enhance biological activity in the water column, promoting phytoplankton growth and potentially leading to eutrophication if nutrient inputs are excessive.

Conclusion

The present study highlights significant variability in phytoplankton composition, abundance, and distribution across different water bodies and seasons. These differences align with previous findings that variations in phytoplankton communities are influenced by environmental factors such as nutrient availability, light penetration, water temperature, and anthropogenic activities. Seasonal changes and local conditions, including water stratification and nutrient influx, play crucial roles in shaping phytoplankton populations. The study also corroborates earlier research linking higher phytoplankton density to periods of intense sunlight, which enhances photosynthetic activity. Similarly, observed correlations between environmental parameters (e.g., temperature, dissolved oxygen, and nutrients) and plankton communities emphasize the interconnectedness of abiotic factors in aquatic ecosystems.

These findings reinforce the importance of monitoring water quality parameters to manage and protect aquatic ecosystems effectively. Moreover, understanding phytoplankton dynamics is vital for maintaining the ecological balance and productivity of freshwater systems, particularly in regions where they contribute to primary production and serve as a key food source for aquatic organisms.

Conflict of Interest Statement

The authors have no conflicts of interest to declare. All co-authors have seen and agree with the contents of the manuscript and there is no financial interest to report. We certify that the submission is original work and is not under review at any other journal for publication.

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