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RESEARCH ARTICLE

ECOLOGICAL ASSESSMENT OF PHYTOPLANKTON IN RELATION TO WATER PHYSICO-CHEMICAL PARAMETERS IN THE BAYS OF THE ÉBRIÉ LAGOON, COTE D'IVOIRE

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Abstract

The Ebrié Lagoon plays a critical role in biodiversity conservation and supports key local activities such as fisheries and tourism. However, rapid urbanization in surrounding districts (Cocody, Koumassi, Vridi, Plateau)has contributed to increasing pollution and ecological disturban ces.This study assessed the relationship between physicochemical para meters and phytoplankton abundance in selected bays of the lagoon. From February to November 2020, samples were collected using vials and a 20 µm mesh plankton net in areas exposed to strong anthropogeni c pressure.A total of 53 taxa,distributed across five phyla(Heterokontop hyta, Dinophyta, Cyanoprokaryota, Euglenophyta, Chlorophyta), were identified. A bloom of Skeletonemacostatum occurred at the Vridi Zimbabwe station during the short rainy season, while phytoplankton abundances remained low during the major rainy season. The results revealed strong spatial and seasonal variability in physicochemical parameters,driven by river inputs,marine intrusions,and human activitie s. These findings indicate that phytoplankton distribution in the Ebrié Lagoon is highly dependent on environmental conditions, providing insights into the dynamics of primary production in this vulnerable ecosystem.

Introduction:-

Phytoplankton consists of photosynthetic microorganisms passively transported by wind and currents. They occur in suspension within the euphotic zone of oceans, as well as in freshwater (lakes, rivers) and brackish environments (Callamare, 2009). Lagoons cover about 13% of the world's coastlines (Cromwell, 1971) and represent ecosystems of outstanding ecological and socio-economic importance (Kjerfve, 1994). They are characterized by high biological

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richness and serve as areas of intense and diversified human exploitation (Lacaze, 1996). These systems are among the most productive environments, playing a crucial role in the life cycle of many species, including fish, mollusks, crustaceans, and migratory birds (Komoé, 2010). Owing to their diversity and accessibility, lagoons have long supported human settlements and sustain multiple activities such as aquaculture, fisheries, tourism, industry, and plantation agriculture (Ouattara, 2017). While these activities contribute to socio-economic development, they also exert increasing pressure on lagoon ecosystems. In Côte d'Ivoire, development needs have generated practices that directly threaten the sustainability of aquatic ecosystems (Gourène et al., 1999). Within this context, phytoplankton studies are of particular relevance, as this community forms the basis of primary production and serves as a sensitive indicator of water quality. The present study aims to assess the influence of physicochemical parameters on phytoplankton abundance in selected bays of the Ebrié Lagoon, with the ultimate goal of improving the understanding of primary production dynamics in this ecosystem.

Materiel and Methods:-

Study Area:

The Ebrié Lagoon, covering an area of 566 km² with an average volume estimated at 2,7.109 m^3, is the largest lagoonal system in Côte d'Ivoire. It also represents the most extensive coastal ecosystem in West Africa (Guiral&Ferhi, 1989;Scheren et al., 2004). The lagoon stretches for approximately 130 km along the coastline, between 3°40′ and 4°50′ W longitude and 5°10′ and 5°20′ N latitude. Sampling was conducted at four stations distributed across the lagoon (Figure 1): Koumassi**,** a site characterized by dredging activities and traditional soap production; Cocody-Blockhaus, a densely populated area with intense cassava flour processing; Plateau**,** located near the Société de Transport Lagunaire (STL) terminal; and Vridi-Zimbabwe, a port zone adjacent to a large fishing community.

Figure 1. Sampling stations in the Ebrié Lagoon, Côte d'Ivoire

Physicochemical Parameter Analysis:

Measurements of temperature, pH, dissolved oxygen, and salinity were performed in situ using a portable HANNA HI 9829 multi-parameter probe.For nutrient analysis, surface water samples were collected at a depth of 50 cm using 500 ml plastic bottles. The samples were immediately placed in coolers for preservation and transported to the chemistry laboratory of the C.R.O. for analysis. Nutrient concentrations were determined using a Hach-Lange DR-6000 spectrophotometer.

Microalgae Sampling:

Phytoplankton communities were sampled from various stations in the Ebrié Lagoon using a 20 µm mesh plankton net. Surface water was collected with a 15-liter bucket and poured through the net ten times. The resulting concentrated samples were collected in 50 mL vials prepared for this purpose. For preservation, commercial formaldehyde, neutralized to a pH of 7, was added to each sample at a final concentration of 5%.

Phytoplankton Observation, Identification and Enumeration:

Observation was performed in the laboratory. A drop of the homogenized sample was taken from the sedimented portion of the vial using a pipette and mounted on a glass slide with a coverslip. This preparation was then placed on the stage of a light microscope (Olympus CXK 41) for examination.Phytoplankton species were identified using standard taxonomic keys and reference works, including those by Compère (1974), Adou (1999), Komoé (2010), Seu-Anoï (2012), and Konan (2014). Species descriptions were based on the classification system of Van den Hoek et al. (1995), supplemented by the aforementioned taxonomic references.Phytoplankton enumeration was carried out using a Malassez counting chamber. This chamber has a calibrated depth and grid system that allows accurate determination of the observed volume. Each square of the grid is subdivided into 4 rows and 5 columns, corresponding to a volume of:

$V = 0{,}2 \times 0{,}25 \times 0{,}2 = 0{,}01\ mm^3 = 10^{-5}$ ml

Prior to use, the edges of the cover slip were moistened to ensure proper adhesion. The cover slip was then carefully placed on the counting chamber and slightly moved to achieve uniform contact. A drop of the sample was applied to the edge of the cover slip using a micropipette, allowing the liquid to fill the chamber by capillary action.The chamber was placed on the microscope stage. An initial focus was made using the ×40 objective, followed by refinement at ×100 to obtain a clear view of the grid. Phytoplankton cells were enumerated along the grid lines according to the standard Malassez chamber counting method.

Statistical Data Analysis:

Statistical analyses to examine the relationship between phytoplankton species distribution and physicochemical parameters were performed using the CANOCO software (Canonical Community Ordination, version 4.5).Within this software, a Detrended Correspondence Analysis (DCA) was first conducted on the species data to determine the gradient length in standard deviation (SD) units. A linear method is preferred over a unimodal method when the maximum gradient length is less than 4 SD. Consequently, Redundancy Analysis (RDA), a direct gradient multivariate analysis technique, was selected as the most appropriate method for this study. The suitability of RDA for floristic and ecological data has been demonstrated by several authors (Muylaert et al., 1997; O'Farrell et al., 2007).

Results:-

Physico chemical Parameters:

Water temperatures ranged from 26.2 °C (during the short dry season) to 30.3 °C (during the short rainy season), indicating generally warm conditions in the Ebrié Lagoon. Salinity exhibited high spatial and seasonal variability, from 1.2 PSU (Station 1, major dry season) to 20.36 PSU (Station 4, short dry season), reflecting the combined influence of freshwater river inputs and marine intrusions.The pH ranged from 5.66 to 7.54, indicating slightly acidic to neutral waters overall.

Minimum values were recorded during the short dry season (Station 2), while maximum values occurred during the short rainy season (Station 4). Dissolved oxygen concentrations varied from 3.93 to 5.92 $mg \cdot L^{-1}$. The lowest concentrations were observed during the major dry season (Station 4), suggesting reduced re-oxygenation under these conditions. Water transparency, measured as Secchi depth, fluctuated between 0.39 m (Station 1, major dry season) and 1.59 m (Station 4, short dry season). The lower transparency indicated higher turbidity in certain areas, likely related to terrigenous inputs.

Regarding nutrients, nitrate (1.2–6.2 $mg \cdot L^{-1}$) and nitrite (0.027–0.47 $mg \cdot L^{-1}$) concentrations showed marked fluctuations. Their peak values were recorded at Station 4 during the major dry season and the short rainy season, respectively. Ammonium reached a maximum of 1.02 $mg \cdot L^{-1}$ (Station 4, major rainy season), compared to a minimum of 0.13 $mg \cdot L^{-1}$ (Station 1, short dry season). Orthophosphate concentrations (0.14–0.88 $mg \cdot L^{-1}$) exhibited contrasting values across stations during the major dry season, indicating spatially variable remineralization dynamics. Finally, silica levels varied from 0.116 to 9.85 $mg \cdot L^{-1}$, with peak values during the short rainy season (Station 1) that were likely associated with continental inputs.

Microalgal Community Composition:

Microscopic examination of the phytoplankton community in the study area revealed 53 taxa, distributed across 5 divisions, 7 classes, 20 orders, 26 families, and 34 genera (Table 1).The Heterokontophyta exhibit the highest diversity, comprising 31 taxa, or 58% of the total count. Following them are the Dinophyta with 9 taxa (17%), Cyanoprokaryota with 6 taxa (11%), Chlorophyta with 4 taxa (8%), and Euglenophyta with 3 taxa (6%) (Figure 2).

Table 1:Distribution of taxa by station (St1: Koumassi ; St2: Plateau ; St3: Cocody ; St4: Vridi).

Taxons	St1	St2	St3	St4
Cyanoprokaryota				
Cyanophyceae				
Oscillatoriaceae				
Oscillatoria limosa			x	x
Oscillatoria anguinis	x	x	x	
Oscillatoria sp.	x	x		
Spirulina major	x	x		
Chroococcaceae				
Chroococcusdispersus		x	x	
Microcystis sp.	x		x	
Heterokontophyta				
Coscinodiscophyceae				
Melosiraceae				
Aulacoseirasp.		x	x	x
Melosiraitalica		x	x	
Heliopeltaceae				
Actinoptychusadriaticus			x	x
Coscinodiscaceae				
Coscinodiscus asteromphalus	x	x	x	x
Coscinodiscus marginatus	x	x	x	x
Coscinodiscus sp.	x		x	
Rhizosoleniaceae				
Rhizosoleniabergonii			x	
Guinardiaflaccida			x	
Guinardia striata		x		
Pseudosolenia calcar-avis			x	
Skeletonemaceae				
Skeletonemacostatum	x	x	x	x
Mediophyceae				
Anaulaceae				
Terpsinoemusica		x	x	
Attheyaceae				
Attheyasp.			x	
Bellerocheaceae				
Climacodiumfrauenfeldianum			x	
Chaetocerotaceae				
Chaetoceros brevis			x	
Chaetoceroscurvisetus			x	x
Chaetoceroscompressus			x	x
Chaetocerosdecipiens			x	x
Chaetoceroslauderi			x	
Chaetoceros subtilis			x	x
Chaetocerossp.1			x	
Chaetocerossp.2		x	x	
Chaetocerossp.3			x	

Hemiaulaceae				
Hemiaulussp.			x	
Lauderiaceae				
Lauderiaannulata		x		
Triceratiaceae				
Odontella sinensis			x	
Paraliaceae				
Paraliasp.	x	x	x	
Bacillariophyceae				
Naviculaceae				
Donkiniasp.	x			
Pleurosigmataceae				
Gyrosigmabalticum	x			x
Surirellaceae				
Surirellasp.1	x	x	x	
Surirellasp.2			x	x
Euglenophyta				
Euglenophyceae				
Euglenales				
Euglenaceae				
Phacuslongicauda			x	x
Euglena proxima	x			
Trachelomonas scabra	x		x	
Chlorophyta				
Chlorophyceae				
Chlorococcales				
Hydrodictyaceae				
Pediastrum duplex	x		x	
Scenedesmaceae				
Coelastrum sp.			x	
Desmodesmusdisciformis			x	x
Desmodesmusquadricauda			x	
Dinophyta				
Dinophyceae				
Protoperidiniaceae				
Protoperidiniumsp.1			x	x
Protoperidiniumsp.2	x		x	
Protoperidinium sp.3			x	x
Pyrophacaceae				
Pyrodinium sp.			x	x
Dinophysaceae				
Dinophysiscaudata		x		x
Dinophysisrotundata		x	x	
Prorocentraceae				
Prorocentrummicans		x	x	
Ceratiaceae				
Ceratiumfurca			x	x

Podolampadaceae				
Podolampassp.			x	x
Total = 53	**15**	**18**	**45**	**20**

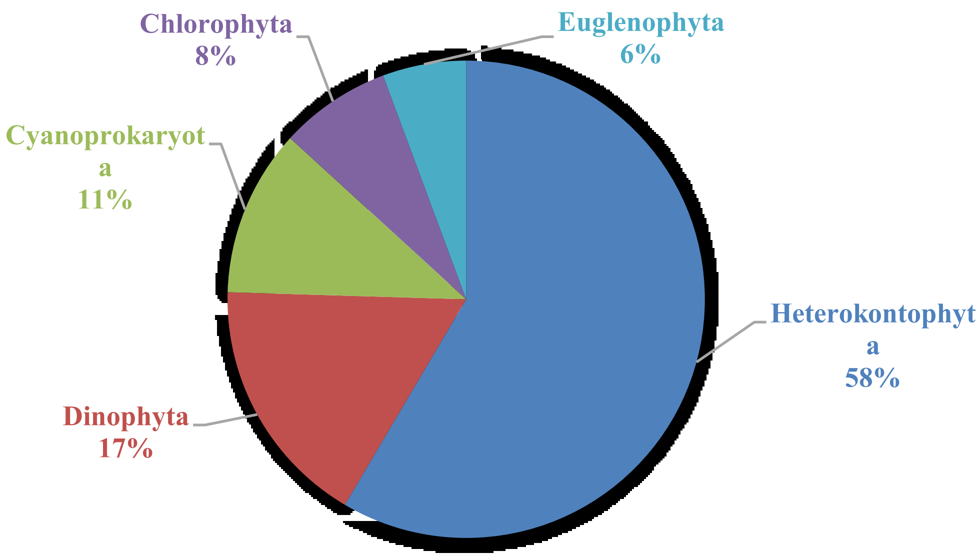

Figure 2: Proportion of the different phyla observed in the Ebrié Lagoon

Phytoplankton Density:
Analysis of phytoplankton densities in the Ebrié Lagoon revealed a clear dominance of Bacillariophyta (9.07×10^5 cells/L) and Cyanoprokaryota (4.17×10^5 cells/L). The abundances of other divisions were considerably lower: Chlorophyta (1.82×10^5 cells/L), Dinophyta (5.32×10^4 cells/L), and Euglenophyta (1.00×10^5 cells/L).Spatially, the highest total abundance was recorded at Station 4 (8.59×10^8 cells/L), followed by Station 3 (4.48×10^7 cells/L), Station 2 (3.34×10^7 cells/L), and Station 1 (1.42×10^7 cells/L). Seasonally, the highest density was observed during the short rainy season (8.60×10^8 cells/L), followed by the major dry season (4.99×10^7 cells/L), the major rainy season (2.79×10^7 cells/L), and finally the short dry season (1.29×10^7 cells/L).

Station-Specific Dynamics :
Koumassi (St1): Absolute densities ranged from 6.20×10^5 cells/L (short dry season) to 6.02×10^6 cells/L (short rainy season) (Figure 3).The Cyanoprokaryota and Heterokontophyta (Bacillariophyta) were the predominant divisions(Figure 4).The high abundances within these groups were primarily driven by the species Oscillatoria sp.an d Skeletonemacostatum, respectively.

Plateau (St2): Absolute density oscillated between 1.40×10^6 cells/L (short rainy season) and 2.28×10^7 cells/L (major dry season) (Figure 5). With the exception of the major rainy season, which showed a high density of Cyanoprokaryota, the Heterokontophyta were predominant throughout all other seasons (Figure 6). The dominance was attributed to Skeletonemacostatum (Heterokontophyta) and Microcystis sp. (Cyanoprokaryota during the major rainy season).

Cocody (St3): Densities varied from 2.92×10^6 cells/L (short rainy season) to 1.74×10^7 cells/L (major dry season) (Figure 7). The Cyanoprokaryota were dominant during the major and short rainy seasons, whereas the Heterokontophyta were dominant during the major and short dry seasons (Figure 8). The high counts were again linked to Skeletonemacostatum (Heterokontophyta) and Oscillatoria sp.2 (Cyanoprokaryota).

Vridi-Zimbabwe (St4): Spatio-temporal distribution of absolute densities varied widely, from 6.12 × 10^5 cells/L (major rainy season) to 8.50 × 10^8 cells/L (short rainy season) (Figure 9). The Heterokontophyta were the predominant division across all seasons. However, a distinct peak of Cyanoprokaryota was observed during the short dry season (Figure 10).

Figure 3: Total phytoplankton density variations at the Koumassi station

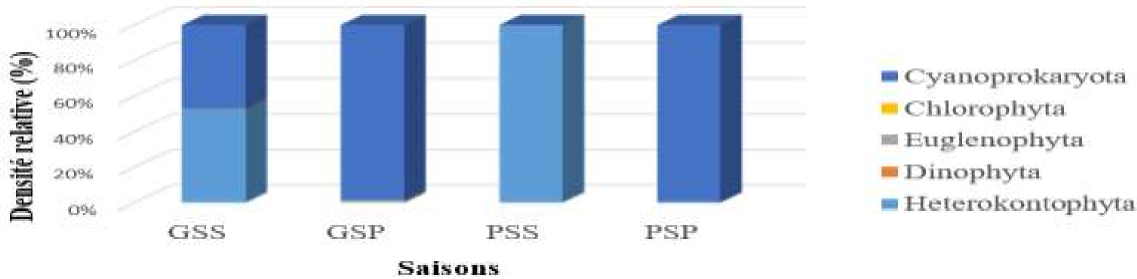

Figure 4: Relative phytoplankton density variations at the Koumassi station

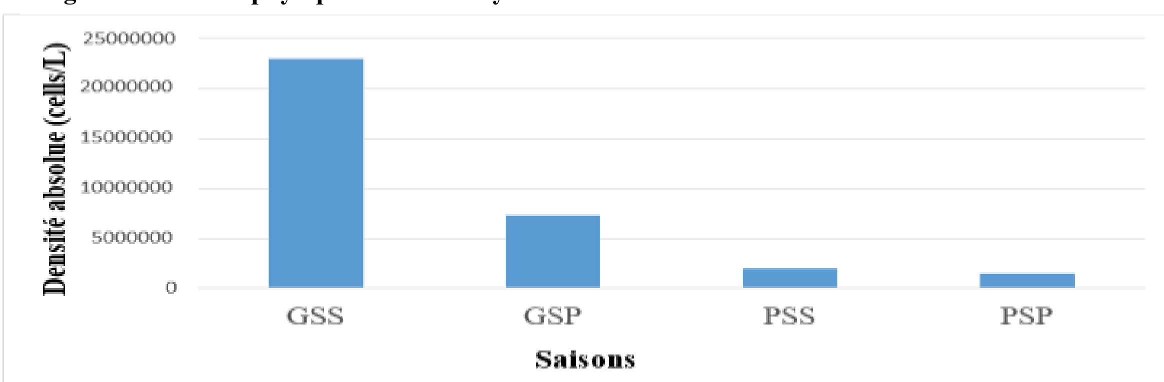

Figure 5: Total phytoplankton density variations at the Plateau station

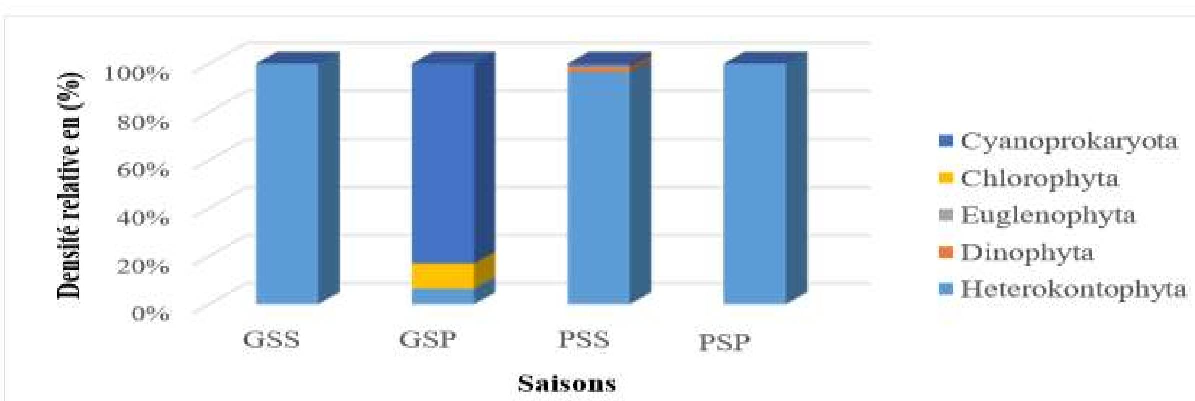

Figure 6:**Relative phytoplankton density variations at the Plateau station**

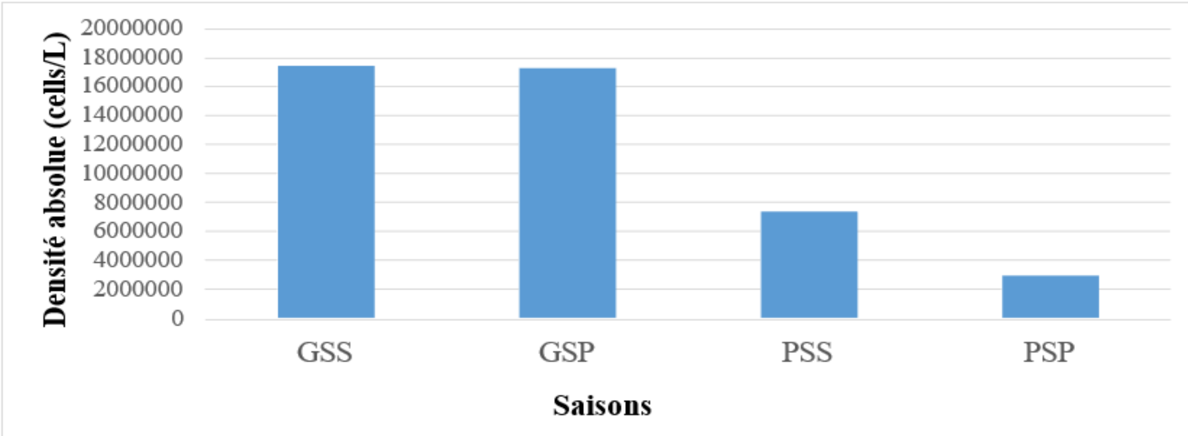

Figure7:**Total phytoplankton density variations at the Cocody station**

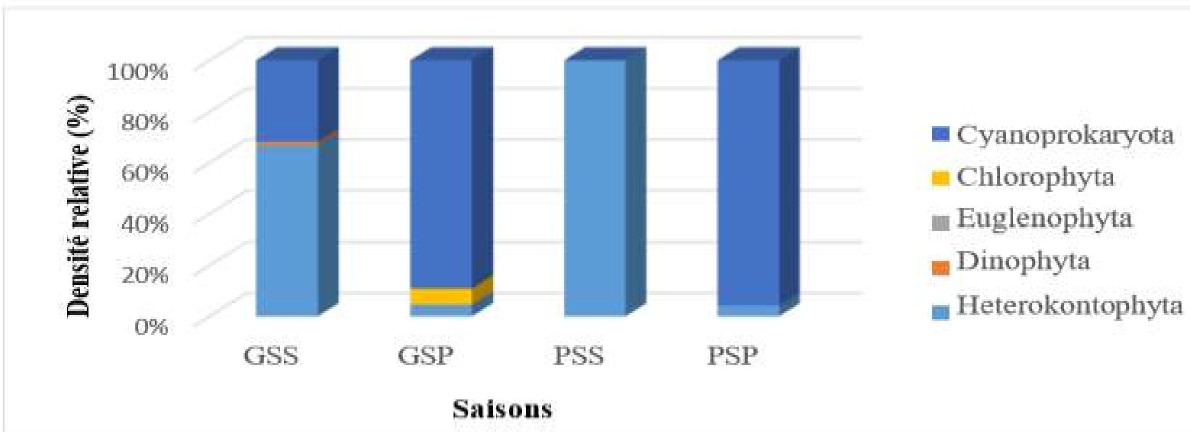

Figure 8:**Relative phytoplankton density variations at the Cocody station**

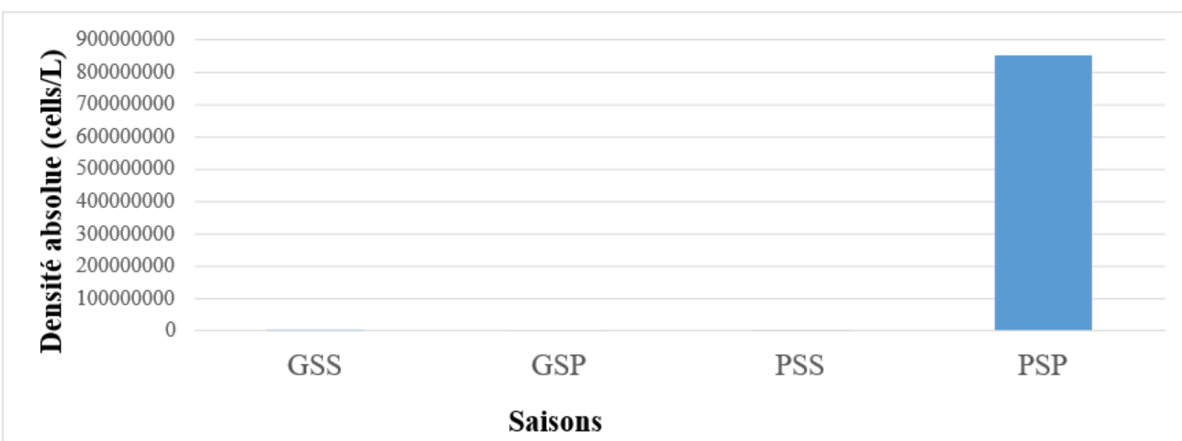

Figure9:**Total phytoplankton density variations at the Vridi-Zimbabwestation**

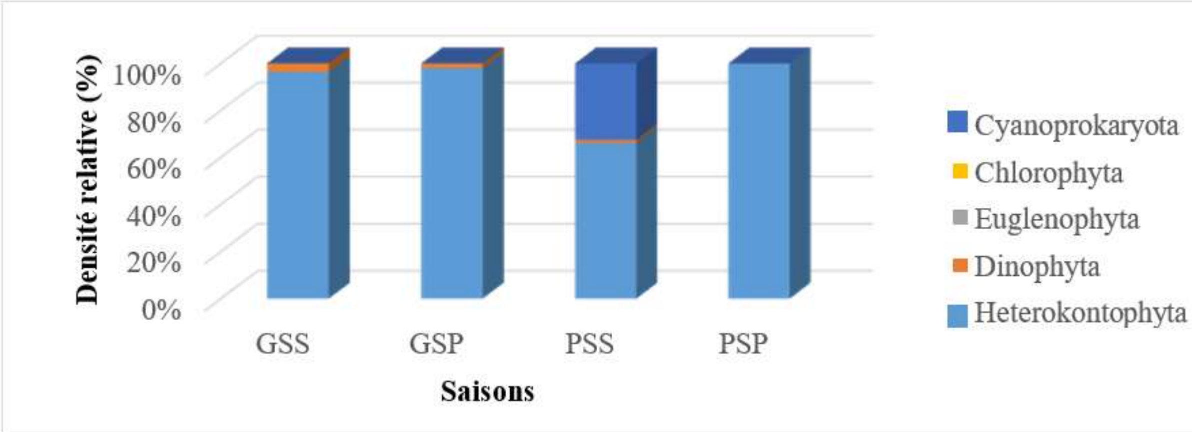

Figure10:Relative phytoplankton density variations at the Vridi-Zimbabwestation

Correlation between Physicochemical Parameters and Phytoplankton Taxa:-

To investigate the correlation between physicochemical parameters and phytoplankton taxon abundance, a redundancy analysis (RDA) was performed.Axis I was positively correlated with nitrate, nitrite, and orthophosphate concentrations, and negatively correlated with temperature, silica, pH, and dissolved oxygen and ammonium concentrations. Axis II was positively correlated with pH, silica, temperature, and orthophosphates, and negatively correlated with dissolved oxygen, ammonium, nitrate, and nitrite.

The ordination plot of factorial axes I and II delineated four distinct phytoplankton community groups associated with specific environmental conditions (Figure 11).

GroupI comprised Chaetoceroscurvisetus (chcu), Coscinodiscusmarginatus (coma),Coscinodiscus asteromphalus (coas), and Paralia sp. (pasp). These species were observed at all stations during the major dry season and were influenced by orthophosphate levels.

Group II consisted of Aulacoseira sp. (ausp), Oscillatoria sp.1 (ossp1), and Skeletonemacostatum (skco). These taxa were present at the Koumassi station during the short dry season, and their distribution was associated with nitrate concentration.

Group III was characterized by taxa such as Lauderiaannulata (laan), Melosiraitalica (meit), and Oscillatoria sp.3 (ossp3). These taxa were found at all stations and during all seasons except the major dry season. Their occurrence was influenced by water transparency, salinity, dissolved oxygen, and ammonium.

Group IV included Pediastrum duplex (pedu) and Microcystis sp. (misp), which appeared at the Plateau, Koumassi, and Cocody stations during the major rainy season. The distribution of these taxa was associated with silica concentration, temperature, and pH.

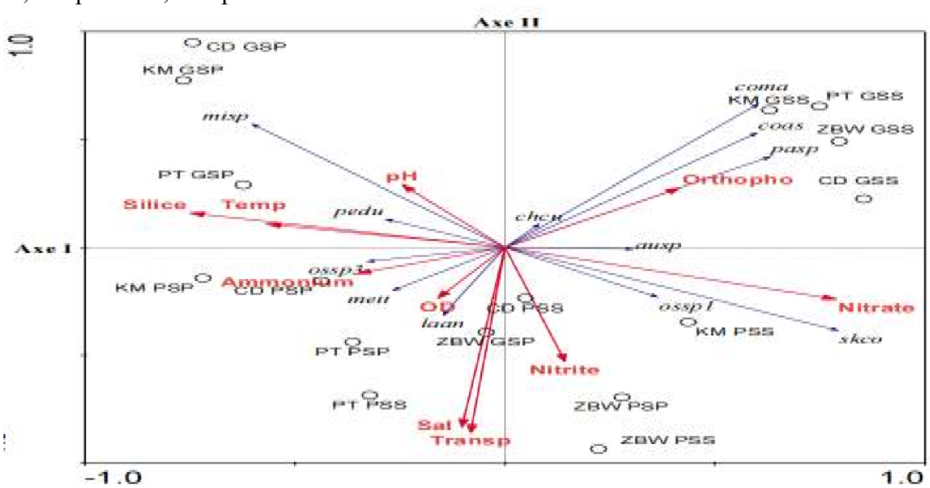

Figure10:**Correlations of physicochemical parameters with phytoplankton taxa**

Discussion:-

The observed spatio-temporal variations in physicochemical parameters within the Ébrié Lagoon bays reflect the strong combined influence of riverine inputs, marine intrusions, and local anthropogenic pressures. The relatively highwater temperatures (26.2–30.3 °C) indicate a typical tropical environment, favorable for phytoplankton development. Similar thermal patterns have been reported in the Aby Lagoon (Amon et al., 2019) and the Grand-Lahou Lagoon (Kouassi et al., 2012), confirming the thermal stability of Ivorian lagoon systems.The high salinity variability (1.2–20.36 PSU) reflects dynamic interactions between freshwater discharges and marine intrusions. These fluctuations are characteristic of Ivorian lagoons (Gourène et al., 1999; Aka et al., 2000) and align with observations in other tropical systems (Kjerfve, 1994; Kennish, 2002).

The pH range (5.66–7.54) indicates slightly acidic to neutral waters, conditions potentially resulting from enhanced organic matter decomposition and terrigenous inputs rich in humic acids, as observed in the Ébrié Lagoon by Kouassi et al. (2015).Dissolved oxygen levels (3.93–5.92 $mg \cdot L^{-1}$) were moderate, sometimes nearing critical thresholds for sensitive aquatic organisms. The decrease recorded during the major dry season may be attributed to intensified respiration and mineralization processes, a phenomenon also reported in other tropical lagoons (Nzualo, 2010; Boyd, 1990). Water transparency (0.39–1.59 m) revealed high turbidity at some stations, likely resulting from terrigenous inputs, sediment resuspension, and human activities (Ouattara, 2017). This factor is critical for light penetration and photosynthesis and may locally limit primary productivity (Wetzel, 2001).Nutrient concentrations showed considerable heterogeneity.

Elevated nitrate (up to 6.2 $mg \cdot L^{-1}$) and nitrite (up to 0.47 $mg \cdot L^{-1}$) levels suggest continental and anthropogenic inputs, particularly from domestic and agricultural discharges (Gourène et al., 1999; Arfi et al., 2001). Orthophosphate concentrations (0.14–0.88 $mg \cdot L^{-1}$) indicate intense remineralization processes, comparable to observations in the Aby Lagoon (Amon et al., 2019). High silica levels during the short rainy season (up to 9.85 $mg \cdot L^{-1}$) underscore significant terrigenous inputs, confirming its role as a key nutrient for diatom development (Reynolds, 2006; Komoé, 2010).

Collectively, these results confirm that the Ébrié Lagoon is a highly productive system subject to significant anthropogenic pressure. The observed spatio-temporal patterns are consistent with the dynamics of Ivorian lagoons (Aka et al., 2000; Kouassi et al., 2012) and align with other tropical lagoon ecosystems where primary productivity is strongly governed by external inputs and hydrological variability (Kjerfve, 1994; Kennish, 2002). These conditions create a favorable environment for phytoplankton growth, but nutrient excesses may heighten the risks of eutrophication, as previously reported in the Aby and Grand-Lahou lagoons (Amon et al., 2019; Kouassi et al., 2015).

Phytoplankton in the Ébrié Lagoon exhibits significant seasonal growth rate variations leading to abundance shifts (Seu-Anoï et al., 2013). The peak phytoplankton abundance during the short rainy season at Station 4 was driven by a bloom of Skeletonemacostatum (skco). This high density may be due to organic matter decomposition from rainfall, enriching the water column with nutrients. Indeed, nutrient availability is a primary factor controlling phytoplankton growth and biomass (Caron et al., 2000).In this study, Heterokontophyta represented the group with the highest phytoplankton density. These findings align with those of Komoé (2010) in the Grand-Lahou Lagoon but contrast with Seu-Anoï (2012), who also reported high densities of Heterokontophyta in the Ébrié Lagoon.

Conversely, low phytoplankton abundances were observed during the major rainy season. These are likely more related to dilution processes than to nutrient inputs from rivers (Pikaitytë et al., 2004). Furthermore, as noted by Seu-Anoï et al. (2013), the brown river water during this season enriches the lagoon with organic matter, reducing water transparency and potentially diminishing algal growth rates. Additionally, high freshwater discharge can flush phytoplankton biomass seaward, preventing bloom development (Bonilla et al., 2005). In the Ébrié Lagoon, the substantial freshwater inflow during the major rainy season likely prevents biomass accumulation, flushing it offshore.The low phytoplankton abundances during the major rainy season in the Ébrié Lagoon contrast with the typical pattern in many tropical lagoons, where phytoplankton abundance is positively correlated with riverine nutrient inputs (Hlaili et al., 2007). This anomaly, also reported by Seu-Anoï et al. (2013) for this lagoon, highlights its unique hydrological forcing.

The distribution of microscopic plant species in nature is always governed by biological and ecological factors. As demonstrated by Schulze and Caldwell (1995), each phytoplankton species has its own optimal growth conditions, and its density is primarily due to its adaptation to the physicochemical parameters of the environment. In our study, redundancy analysis showed that physicochemical parameters play a major role across the stations of the Ébrié Lagoon, as they drive the growth of phytoplankton taxa. Our results indicate that the studied taxa are influenced by all the measured physicochemical parameters.

Conclusion:-

This study analyzed the phytoplankton community in the Ébrié Lagoon and its relationship with physicochemical parameters. We identified 53 taxa across 5 divisions, 7 classes, 20 orders, 26 families, and 34 genera, with community structure showing strong seasonal variation. A bloom of Skeletonemacostatum occurred at Vridi-Zimbabwe during the short rainy season, while the lowest abundances were recorded during the major rainy season, likely due to dilution and flushing rather than nutrient limitation.

Redundancy analysis revealed that spatio-temporal phytoplankton distribution is primarily governed by nutrient concentrations, salinity, transparency, and pH. These findings highlight the community's sensitivity to both natural hydrological cycles and anthropogenic influences. The single-species dominance during blooms and the system's negative response to rainy season inputs underscore its ecological complexity and vulnerability to eutrophication. This work provides a critical baseline for future monitoring and management of this ecosystem.

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