Applied Ecology and Environmental Sciences, 2026, Vol. 14, No. 1, 1-6
Available online at http://pubs.sciepub.com/aees/14/1/1
Published by Science and Education Publishing
DOI:10.12691/aees-14-1-1

Phytoplankton Assemblages As Bioindicators of Pollution Stress in the Cotonou Lagoon, Benin

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Received December 24, 2025; Revised January 26, 2026; Accepted February 02, 2026

Abstract Anthropogenic pollution, particularly the discharge of untreated urban wastewater, increasingly threatens the ecological integrity of coastal lagoons. The study assessed the phytoplankton community of the Cotonou Lagoon (southern Benin) during the major dry season (December-March) where wastewater inputs are most pronounced, to infer water-quality status using phytoplankton bioindicators. Phytoplankton was sampled monthly at six stations using a 25 µm mesh plankton net from December to March at six stations using a 25 µm mesh plankton net, and identified by light microscopy based on standard taxonomic keys. A total of 63 phytoplankton species (50 genera, 8 classes and 5 phyla) were recorded, with diatoms (Bacillariophyceae, Coscinodiscophyceae and Mediophyceae) strongly dominating the assemblage and marine taxa prevailing, indicating marked Atlantic Ocean water intrusion. The widespread occurrence of taxa associated with organic pollution and eutrophic conditions (*Anabaena*, *Aphanizomenon*, *Microcystis*, *Phormidium*) suggests degraded water quality linked to nutrient enrichment of the lagoon waters. In addition, several potentially harmful taxa (e.g. Dinophysis caudata, *Prorocentrum gracile*, *Microcystis viridis* and *Pseudo-nitzschia delicatissima*) highlight a possible risk of bloom-related ecological impacts and public-health concerns through fisheries consumption. These findings support the need for improved wastewater management and sustained monitoring to guide restoration efforts.

Keywords: *Bioindication, microalgae, coastal environment, biodiversity*

Cite This Article: Dogbè Clément Adjahouinou, Elias Alexandre Sètondji Adanlokonon, Gildas Djidohokpin, Sètondé Baptiste Karen Dossoukpèvi, Zacharie Sohou, and Elie Montchowui, "Phytoplankton Assemblages As Bioindicators of Pollution Stress in the Cotonou Lagoon, Benin." *Applied Ecology and Environmental Sciences*, vol. 14, no. 1 (2026): 1-6. doi: 10.12691/aees-14-1-1.

1. Introduction

Surface fresh and brackish waters provide important fisheries resources and thus support food security and livelihoods for human populations. Coastal lagoons, are productive transitional ecosystems whose biodiversity and functioning are shaped by the interaction between freshwater inflows and marine waters [1]. Unfortunately, these valuable ecosystems are increasingly affected by anthropogenic pollution associated with rapid urbanisation and land-use change [2,3]. This progressively degrades the habitats and disrupts biodiversity, particularly phytoplankton communities the base of the lagoon food networks [4]. Pollutants inputs can drive eutrophication, leading to major changes in phytoplankton diversity, composition and abundance [5,6]. Consequently, phytoplankton is widely used as bioindicator of water quality and ecological status [7,8].

In Benin, the Cotonou Lagoon receives substantial loads of untreated urban wastewater conveyed by numerous stormwater sewers and drains, resulting in chronic organic and nutrient enrichment [9,10]. This study therefore surveyed the phytoplankton community of the Cotonou Lagoon during the major dry season, characterised by high wastewater inputs, to appraise water quality and ecological implications using phytoplankton bioindicators.

2. Material and Methods

2.1. Study Area

This study was conducted in the Cotonou Lagoon, a narrow channel approximately 4.5 km long and 300 m wide that connects Lake Nokoué to the Atlantic Ocean [11] (Figure 1). The lagoon receives discharges numerous sewers and drains carrying a mixture of stormwater and untreated urban wastewater. It also receives wastes from nearby residents and from activities associated with the Dantokpa market (the largest market in Benin) and hospital effluents from the CHU-MEL (Centre Hospitalier Universitaire de la Mère et de l'Enfant "La Lagune").

The city of Cotonou experiences a sub-equatorial climate with a bimodal rainfall regime, characterised by two rainy seasons, each followed by a dry season, over the annual climatic cycle [12].

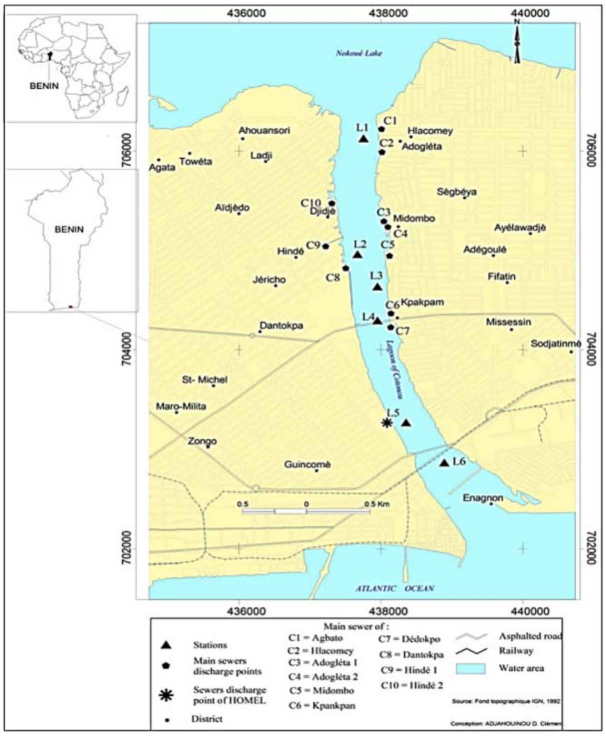


Figure 1. Map of Cotonou city showing the sampling stations and the main sewers outlets location along the lagoon

2.2. Sampling and Analytical Methods

Sampling was conducted monthly during the major dry season (December - March), when stormwater drains and sewers discharge predominantly untreated urban wastewater into the lagoon. In total, four sampling campaigns were carried out at six stations distributed along the entire lagoon (Figure 1).

Phytoplankton samples were collected between 09:00 and 12:00 using a plankton net with a mesh size of 25 µm. At each station, vertical hauls were performed down to the euphotic deph, followed by horizontal tows across the full width of the lagoon to obtain representative samples. The concentrate sample was split into two subsamples: one preserved in the field with 0.5% Lugol iodine solution for organism fixation [13,14], and one kept intact without fixation for the observation and determination of motile or flagellated taxa that may be altered by chemical fixatives [13,15].

In the laboratory, samples were examined using a VWR binocular binocular light microscope at ×100 and ×400 magnification, and at ×1000 (by oil immersion objective) for the smallest taxa. Each sample was analysed in 12 replicate observations improve inventory completeness. Taxonomic identifications were based on microphotographs and standard taxonomic keys [13,15-27]. To strengthen taxonomic reliability, doubtful records were cross-checked against multiple sources and nomenclature was updated using the AlgaeBase taxonomic database [28].

2.3. Data analysis

Species richness (S), defined as the total number of recorded species, was used for taxonomic and spatial comparisons.

Species composition similarity among stations was assessed using the Jaccard index for pairwise station combinations, calculated as follow:

$$J = a/(a + b + c)$$

where a is the number of shared species and, b and c are the numbers of species unique to each station, respectively.

Jaccard index values range from 0 to 1, corresponding to complete dissimilarity (no shared species) and complete similarity (identical species composition), respectively.

3. Results

3.1. Taxonomic Richness of the Phytoplankton Flora of the Cotonou Lagoon

The phytoplankton flora recorded in the Cotonou Lagoon during the study period comprised 63 species, including eight identified only to the genus level. The inventoried taxa belonged to 50 genera, 8 classes (Bacillariophyceae, Dinophyceae, Cyanophyceae, Chlorophyceae, Coscinodiscophyceae, Dictyochophyceae, Mediophyceae and Stylonematophyceae) and 5 phyla (Table 1). Heterokontophyta was the most diversified phylum, with 43 species distributed among 4 classes, including three diatom classes (Bacillariophyceae, Coscinodiscophyceae and Mediophyceae) and Dictyochophyceae. Bacillariophyceae and Mediophyceae showed the highest species richness, with 18 and 17 species, respectively (Figure 2).

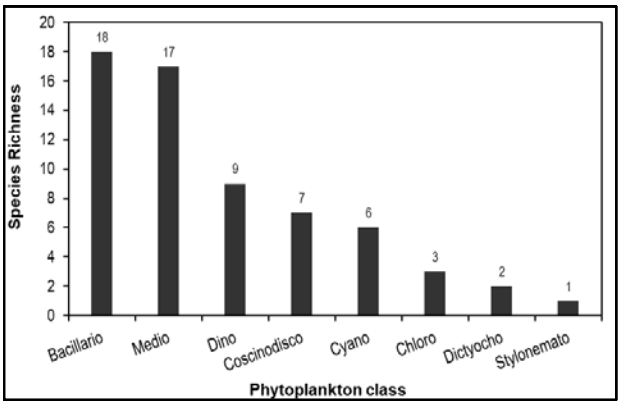
At genus level, Tripos (Dinophyceae) was the most represented, comprising 5 species, followed by *Chaetoceros* and *Hemiaulus*, with 3 species each. Aulacoseira, Entomoneis, Lithodesmium, Pleurosigma, Proboscia, and Ulnaria each comprised 2 species, whereas all other genera were represented by a single species.

Table 1. Inventory, distribution and habitat of phytoplankton species recorded in the Cotonou Lagoon

Phylum	Class	Species	Stations						Habitat
			L1	L2	L3	L4	L5	L6	
Chlorophyta	Chlorophyceae	*Coelastrum* sp.	+	+	-	-	-	-	FW
		Desmodesmus communis (E.Hegewald) E.Hegewald 2000	-	+	+	+	+	+	FW
		Haematococcus sp.	+	-	+	-	-	-	FW
Cyanobacteriophyta	Cyanophyceae	*Anabaena* sp.	+	-	-	-	-	-	BW
		Aphanizomenon sp.	-	+	-	-	-	-	FW
		Geitlerinema sp.	-	-	-	+	-	-	FW
		Gloeotrichia sp.	+	-	+	-	-	-	FW
		Microcystis viridis (A.Braun) Lemmermann 1903	+	+	+	+	+	+	FW
		Phormidium sp.	+	-	-	-	-	-	FW
Dinoflagellata	Dinophyceae	*Dinophysis caudata* Kent 1881	-	-	-	-	+	-	MW
		Gymnodinium sp.	-	-	-	+	-	-	FW and MW
		Prorocentrum gracile F.Schütt 1895	-	+	-	+	-	+	MW
		Protoperidinium divergens (Ehrenberg) Balech 1974	-	+	-	-	+	-	MW
		Tripos furca (Ehrenberg) F.Gómez 2013	-	-	+	+	+	+	MW
		Tripos intermedius (Jørgensen) F.Gómez 2013	+	+	+	+	+	+	MW
		Tripos muelleri Bory 1826	-	-	-	+	-	-	MW
		Tripos pentagonus (Gourret) F.Gómez 2021	-	-	-	-	+	+	MW
		Tripos trichoceros (Ehrenberg) Gómez 2013	-	+	+	+	-	+	MW
Heterokontophyta	Bacillariophyceae	*Asterionellopsis glacialis* (Castracane) Round 1990	+	+	+	+	+	+	MW
		Bacillaria paxillifer (OFMüller) T. Marsson 1901	+	+	+	+	+	+	BW
		Cylindrotheca closterium (Ehrenberg) Reimann & J.C.Lewin 1964	+	-	-	+	+	+	MW
		Entomoneis ornata (Bailey) Reimer 1975	+	+	+	+	+	+	MW
		Entomoneis sulcata Müller, nom. inval. 2009	+	+	+	+	+	+	MW
		Gyrosigma balticum (Ehrenberg) Rabenhorst 1853	+	+	+	+	+	+	MW
		Hobaniella longicruris (Greville) P.A.Sims & D.M.Williams 2018	-	-	-	+	-	-	MW
		Mastogloia lacustris (Grunow) Grunow 1880	-	+	-	-	-	+	FW
		Meuniera membranacea (Cleve) P.C.Silva 1996	+	+	+	+	+	+	MW
		Navicula cryptocephala Kützing 1844	-	+	+	+	+	+	FW MW
		Pinnularia viridis (Nitzsch) Ehrenberg 1843	-	+	+	+	-	-	FW
		Pleurosigma angulatum (J.T.Quekett) W.Smith 1852	+	+	+	+	+	+	MW
		Pleurosigma elongatum W.Smith 1852	+	+	+	+	+	+	MW
		Pseudo-nitzschia delicatissima (Cleve) Heiden 1928	-	+	-	-	-	+	MW
		Surirella striatula Turpin 1828	-	+	+	+	+	+	MW
		Thalassionema nitzschioides (Grunow) Mereschkowsky 1902	+	-	+	+	+	+	MW
		Ulnaria capitata (Ehrenberg) Compère 2001	+	+	+	+	-	+	FW
		Ulnaria ulna (Nitzsch) Compère 2001	-	+	-	+	-	+	FW
	Coscinodiscophyceae	*Aulacoseira granulata* (Ehrenberg) Simonsen 1979	-	-	-	+	-	-	FW
		Aulacoseira spiralis (Ehrenberg) Houk & Klee 2007	+	-	-	-	-	-	FW

Phylum	Class	Species	Stations						Habitat
			L1	L2	L3	L4	L5	L6	
Chlorophyta	Chlorophyceae	*Coelastrum* sp.	+	+	-	-	-	-	FW
		Desmodesmus communis (E.Hegewald) E.Hegewald 2000	-	+	+	+	+	+	FW
		Coscinodiscus radiatus Ehrenberg 1840	+	+	+	+	-	+	MW
		Guinardia striata (Stolterfoth) Hasle 1996	+	+	+	+	+	+	MW
		Paralia sulcata (Ehrenberg) Cleve 1873	+	+	+	+	+	+	MW
		Pseudosolenia calcar-avis (Schultze) B.G.Sundström 1986	+	+	+	+	+	+	MW
		Triceratium favus Ehrenberg 1839	-	-	-	+	-	-	MW
	Dictyochophyceae	*Dictyocha fibula* Ehrenberg 1839	-	-	-	+	-	+	MW
		Octactis octonaria (Ehrenberg) Hovasse 1946	-	-	+	-	-	-	MW
	Mediophyceae	*Chaetoceros atlanticum* Cleve 1873	+	+	+	+	+	+	MW
		Chaetoceros lorenzianus Grunow 1863	+	+	-	-	+	+	MW
		Chaetoceros peruvianus Brightwell 1856	+	+	+	+	+	+	MW
		Ditylum brightwellii (T.West) Grunow 1885	+	-	-	+	+	-	MW
		Helicotheca tamesis (Shrubsole) M.Ricard 1987	-	-	-	+	-	-	MW
		Hemiaulus hauckii Grunow ex Van Heurck 1882	+	+	+	+	+	+	MW
		Hemiaulus chinensis Greville 1865	-	+	+	+	+	+	MW
		Hemiaulus membranaceus Cleve 1873	+	-	-	-	+	+	MW
		Lauderia annulata Cleve 1873	+	+	-	-	+	+	MW
		Lithodesmium undulatum Ehrenberg 1839	-	-	+	+	-	+	MW
		Lithodesmium sp.	-	+	+	+	-	+	MW
		Odontella aurita (Lyngbye) C.Agardh 1832	-	+	-	+	+	+	MW
		Proboscia indica (H.Peragallo) Hernández-Becerril 1995	+	+	+	+	+	+	MW
		Proboscia alata (Brightwell) Sundström 1986	+	-	+	+	+	+	MW
		Thalassiosira aestivalis Gran 1931	+	+	+	+	-	+	MW
		Trieres mobiliensis (Bailey) Ashworth & E.C.Theriot 2013	-	-	+	+	+	-	MW
		Trilamina lobata (Greville) J. Witkowski, P.A.Sims, N.I.Strelnikova & D.M.Williams 2015	-	-	+	-	-	-	MW
Rhodophyta	Stylonematophyceae	*Bangiopsis* sp.	-	-	+	-	-	+	MW
		Total species Richness	33	37	37	45	34	42	

Legend: BW = Brackish water; FW = Freshwater; MW = Marine water
"+" = present; "-" = absent



Bacillario = Bacillariophyceae; Medio = Mediophyceae; Dino = Dinophyceae; Coscinodisco = Coscinodiscophyceae; Cyano = Cyanophyceae; Chloro = Chlorophyceae; Dictyocho = Dictyochophyceae; Stylonemato = Stylonematophyceae

Figure 2. Phytoplankton species richness per class

3.2. Spatial Distribution of the Phytoplankton Community in the Cotonou Lagoon

Species richness per station ranged from 33 (L1) to 45 (L4), with intermediate values of 37 (L2 and L3), 34 (L5) and 42 species (L6). Overall, 26 species were widely distributed across five to six stations, whereas many others occurred at one to four stations (Figure 3).

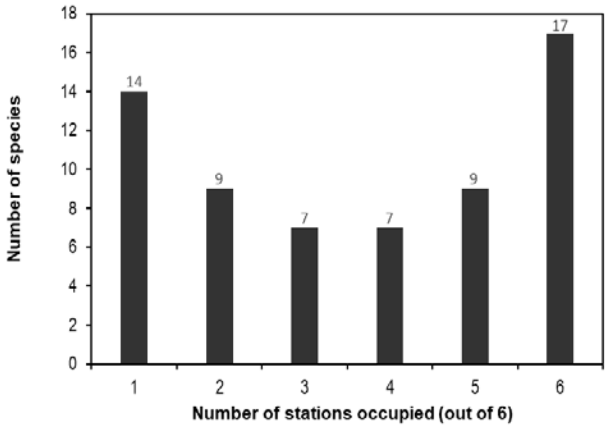


Figure 3. Species occupancy-frequency distribution of phytoplankton in the Cotonou Lagoon during the dry season

Table 2. Jaccard similarity index among sampling station in the Cotonou Lagoon

Stations	L1	L2	L3	L4	L5	L6
L1	1.0					
L2	0.49	1.0				
L3	0.52	0.57	1.0			
L4	0.44	0.58	0.64	1.0		
L5	0.56	0.54	0.54	0.55	1.0	
L6	0.53	0.72	0.65	0.67	0.65	1.0

Species composition similarity among stations assessed using the Jaccard index ranged from 0.44 to 0.72 (Table 2). This indicated moderate to high similarity in phytoplankton assemblages across the lagoon. The highest similarity was observed between stations L2 and L6 (J = 0.72), and L1 and L4 (J = 0.44) exhibited the lowest similarity.

3.3. Habitat Affinity of Phytoplankton Assemblages

Based on habitat affinity, marine species dominated the assemblage with 45 species accounting for 73% of the total species richness. The freshwater and brackish-related species represented a smaller component (Figure 4).

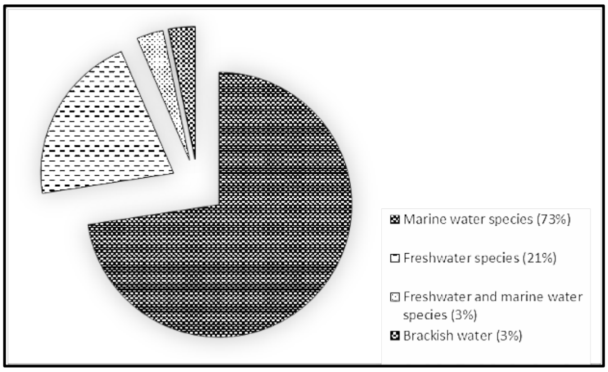


Figure 4. Proportion of phytoplankton species grouped by habitat affinity species in the Cotonou Lagoon

4. Discussion

The phytoplankton flora of the Cotonou Lagoon was dominated by diatoms, mainly Bacillariophyceae together with Mediophyceae and Coscinodiscophyceae. This pattern is consistent with reports from comparable lagoonal and coastal environments, including the Lagos Lagoon, the Iyagbe Lagoon, the Ologe Lagoon and the Majidun tidal creek in Nigeria, and the Boughrara Lagoon, the Aby Lagoon and Grand-Lahou Lagoon [6,29-30]. The predominance of diatoms in lagoonal systems may reflect their planktonic and neritic character and their capacity to exploit hydrodynamic and nutrient conditions typical of these environments [38-40].

Diatoms are widely used as indicators of water quality because many taxa respond to physico-chemical gradients and tolerate broad ranges of conditions [40-43]. Their proliferation is often promoted in nutrient-enriched waters [39,44]. Accordingly, diatom dominance in the Cotonou Lagoon supports an interpretation of eutrophic conditions, further reinforced by the presence of cyanobacterial taxa such *Anabaena*, *Aphanizomenon*, *Microcystis*, *Phormidium*, that are associated with organic pollution and eutrophication in aquatic environments [32,34,45,46].

Beyond eutrophication signals, the strong contribution of marine taxa indicates marked marine influence, most likely through Atlantic Ocean water intrusion during the dry season. Similar seasonal patterns have been reported for the Lagos Lagoon, where marine taxa are more frequent during dry periods [30]. This study findings also agree with [38], who reported *Chaetoceros*, *Coscinodiscus*, *Ditylum* and *Tripos* as frequent genera during the dry season.

The moderate to high similarity among stations (Jaccard index) suggests strong hydrological connectivity and lagoon-wide drivers that can reduce beta diversity [47]. The bimodal occupancy-frequency distribution noticed, highlighted the coexistence of a core assemblage of widespread, tolerant taxa and a pool of locally distributed species shaped by spatial heterogeneity. Widely distributed species were dominated by marine and marine-brackish diatoms, marine dinoflagellates and *Microcystis viridis*. Locally distributed taxa were mainly freshwater chlorophyta, freshwater diatoms and several cyanobacteria, reflecting narrower ecological requirements and sensitivity to salinity intrusion [40,48].

Most Dinoflagellates species recorded are characteristic of warm oceanic waters [49], supporting the influence of Atlantic Ocean waters on the lagoon. *Tripos* was the most species-rich Dinoflagellate genus, as also reported in the Lagos Lagoon [30]. Several Dinoflagellates recorded such as *Dinophysis caudata*, *Gymnodinium* sp. and *Prorocentrum gracile* are toxin-producing species and may therefore represent a potential risk of toxin accumulation in aquatic food webs [50,52]. Others recorded taxa, notably belonging to the genera *Microcystis*, *Anabaena*, *Aphanizomenon*, *Phormidium* and *Pseudo-nitzschia* raised the same risk as they may to release microcystins and neurotoxins [53,55]. The above-mentioned toxin-producing taxa could therefore impair both the lagoon biota and the health of its fishery resources consumers [56]. Moreover, bloom-forming taxa such as *Tripos* spp., together with some diatoms (*Chaetoceros* and *Coscinodiscus*), have been reported to contribute to oxygen depletion and fish gill irritation under bloom conditions [57].

Overall, the phytoplankton structure indicates that the Cotonou Lagoon functions during the major dry season as a heterogeneous transitional ecosystem subjected to both marine forcing and chronic nutrient enrichment notably from urban discharges. This combination promotes the dominance of tolerant taxa while maintaining a pool of locally distributed species.

5. Conclusions

The phytoplankton inventory of the Cotonou Lagoon revealed a pronounced dominance of diatoms and marine-affinity taxa, providing clear evidence of Atlantic Ocean water intrusion during the major dry season. The widespread occurrence of taxa indicative of organic pollution and eutrophic conditions suggests degraded water quality linked to nutrient enrichment, while the presence of potentially harmful taxa points to a risk of bloom-related ecological impacts and potential health concerns via fisheries consumption. Improved wastewater management and sanitation, together with sustained ecological monitoring, are needed to reduce pollution pressure to support lagoon restoration and to prevent public health issues.

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