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Phytoplankton diversity and trophic state of natural water reservoirs in Azagny National Park (Côte d'Ivoire)

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Abstract
Azagny National Park, located 40 kilometres from the town of Grand-Lahou, is home to numerous animal and plant species, including microalgae. The aim of this study was to determine the phytoplankton diversity and trophic status of the water reservoirs in the Azagny National Park. The physico-chemical parameters of the water were measured at stations ST1, ST2 and ST4, from March 2019 to February 2020. Nutrient salts were measured using a spectrophotometer. Phytoplankton sampling was carried out using a plankton net with a mesh size of 20 µm. A total of 134 phytoplankton taxa were inventoried, divided into 5 phyla, 8 classes, 14 orders and 32 families. The waters of the Azagny National Park could be considered rich in taxa, with the majority being Heterokontophyta (48 taxa) and Euglenophyta (39 taxa), followed by Chlorophyta (27 taxa), Cyanoprokaryota (18 taxa) and Dinophyta (2 taxa). Sorensen's index or coefficient of similarity gave values ranging from 0.89 to 0.74, showing that the Park's water reservoirs have taxa distributed in the same way in the different stations. The study also revealed that the park's reservoirs are warm and acidic, with low levels of dissolved oxygen and high levels of nutrient salts (nitrite and phosphate). The A and B index values of 9.81 and 1.62 respectively show that the park's reservoirs are tending towards a state of eutrophy.

Keywords: Diversity, phytoplankton, physico-chemistry, eutrophy, water reservoirs, Azagny

1. Introduction
The degradation of aquatic ecosystems can cause the disappearance or rarefaction of certain species and also lead to the proliferation of certain aquatic organisms or species. In Côte d'Ivoire, these disturbances have been observed in several rivers, lakes and reservoirs, and have had a major impact on aquatic biodiversity (Sweeney *et al*., 2004) [1]. Coastal areas are places of human concentration where the imperatives linked to the development of agriculture and urbanisation threaten the balance of small river ecosystems. Despite studies of aquatic fauna in these regions (Ouattara *et al.*, 2000; Ouattara *et al*, 2007) [2, 3], and those of certain authors in the Adzopé reservoir (Kouassi, 2013; Adon, 2013) [4, 5], in the Fresco lagoon (Konan, 2014) [6], in the Bandama river (Lozo, 2016) [7] and in the Grand-Lahou lagoon complex (Komoé, 2010) [8], data on phytoplankton remain poorly documented. Studies on phytoplankton in Azagny National Park are non-existent. In addition, the Park is subject to various types of anthropogenic pressure that can disrupt its ecological functioning. This lack of knowledge of phytoplankton is a limitation in the management of water reservoirs and the enhancement of this biodiversity. Therefore, this study aims to understand the phytoplankton diversity of the Azagny National Park as well as the trophic status of the waters in order to contribute to the conservation of its biodiversity and guarantee effective and sustainable management of resources.

2. Materials and methods
2.1 Study environment
Azagny National Park is located 130 km from Abidjan, in the prefecture of Grand-Lahou at the mouth of the Bandama River (OIPR, 1981) [9]. The Park covers an area of 19,400 ha and

stretches between two administrative departments (Grand-Lahou and Jacqueville) (Komoé *et al.*, 2008) [10]. The Park is part of the Upper Guinea phytogeographic region, which extends from Togo to Senegal (Atanle *et al.*, 2012) [11]. Four stations (Figure 1) were selected for this study, taking into account their distribution throughout the territory and their accessibility: ST1, ST2, ST3 and ST4.

2.2 Physico-chemical parameters

The physico-chemical parameters of the water (Temp, pH, O2, CND) were measured using a HANNA multiparameter model HI 83200 at the four stations from March 2019 to February 2020. The nutrient salts were analysed in the laboratory and the various concentrations determined using a spectrophotometer. The principle of measurement is based on Beer-Lambert's law, which indicates the proportionality of the optical density with the thickness of the solution (Sample analysed) and the concentration of the chemical element sought.

For the statistical test, the Kruskal-Wallis test was used, which is a non-parametric alternative to the first-order ANOVA (Between groups). It is used to compare at least three samples, and to test the null hypothesis (Significant test at $p<0.05$) that the different samples to be compared come from the same distribution or from distributions with the same median.

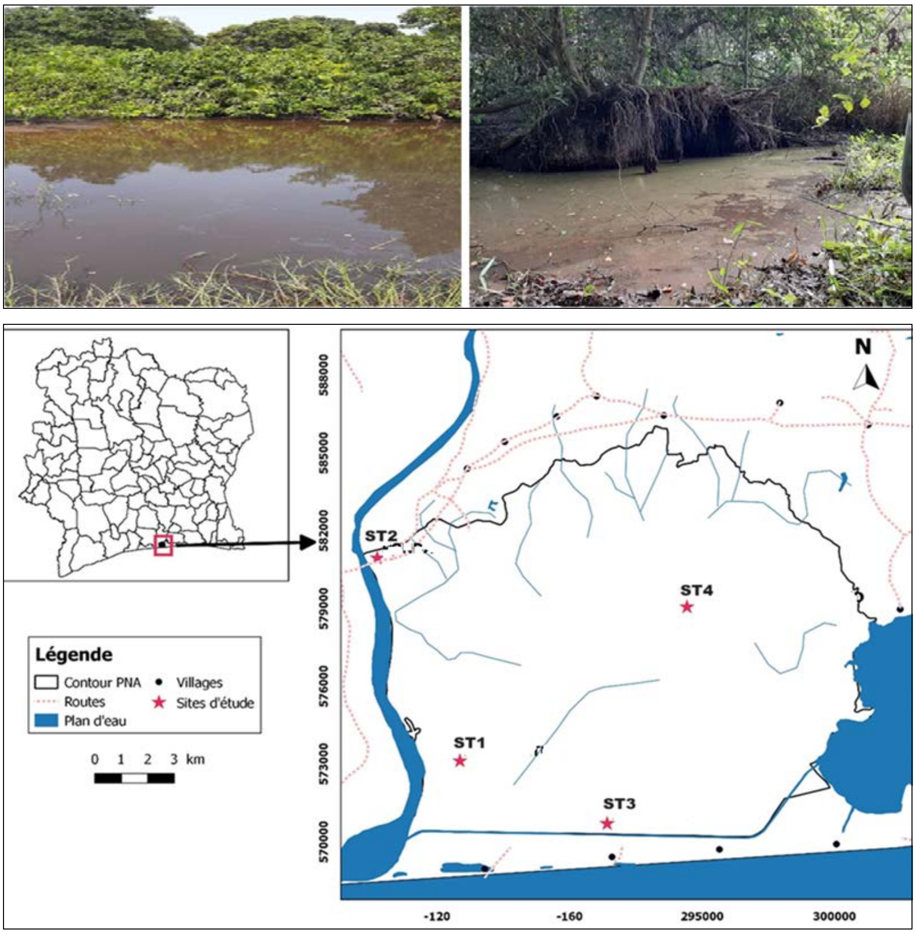

Fig 1: Map of Azagny National Park with sampling stations

2.3. Phytoplankton and trophic status

Phytoplankton were sampled using a 20 µm plankton net at each station. Water samples fixed with 5% formalin were mounted between slide and coverslip and examined under a light microscope with a 40x objective. The different species were identified using various documents (Da, 1992; Ouattara, 2000; Komoé, 2010; Adon, 2013 and Lozo, 2016) [12, 13, 8, 5, 7]. Assessment of the trophic status of the stations was based on examination of the phytoplankton population, for which the absence of a certain number of organisms is as significant as the presence, development or regression of certain species. Three indices (A, B and C) were therefore calculated:

$$A = \frac{\text{Cyanophycées} + \text{Chlorococcales} + \text{Centrales} + \text{Euglenophycées}}{\text{Desmidiacées}}$$

A = composite index

1. 0.3 < A < 1 = oligotrophic environment
2. 1 < A < 2.5 = mesotrophic environment
3. 2.5 < A < 5 = eutrophic environment

A second index (B) based on the quotient of the relative number of Chlorococcales and Desmidiaceae species present in lakes has generally been used to recognize the type of trophy.

$$B = \frac{\text{Chlorococcales}}{\text{Desmidiacées}}$$

B < 1 = oligotrophic environment
B > 1 = eutrophic environment

A third index (C) derived from the Diatoms, translates the ratio of the number of species of the Centrales to that of the Pennales:

$$C = \frac{Centrales}{Pennales}$$

C: 0 - 0.2 = oligotrophic environment
C: 0.2 - 3 = eutrophic environment

3. Results and discussion

3.1 Physico-chemical parameters

Parameters such as temperature (T°), dissolved oxygen (O2), dissolved solids content (TDS), conductivity, depth and transparency varied significantly from one station to another ($p < 0.05$), whereas other parameters such as pH, nitrate content and phosphorus content did not vary ($p > 0.05$). The water in the park's reservoirs is slightly warm (27.68 °C) and acidic, with low levels of dissolved oxygen (3.52 mg/l) and high levels of nutrient salts (Nitrite and phosphate). This could be explained by a number of factors, such as the degree of isolation, wind and plant cover (Canopy), the decomposition of macrophytes and the faeces of animals that drink from the water.

3.2 Phytoplankton diversity

The algal flora of all the environments studied comprises 134 phytoplankton taxa divided into 5 phyla, 8 classes, 14 orders and 32 families (Table I). With a majority of Heterokontophyta (48 taxa or 36%) and Euglenophyta (39 taxa or 29%), followed by Chlorophyta (27 taxa or 20%), Cyanoprokaryota (18 taxa or 13%) and Dinophyta (2 taxa or 2%), Azagny National Park could be considered rich in taxa (Figure 2). This richness could be due to the fact that the waters are stagnant, which favours biological processes such as the complete reproduction and development cycles of algae (Ouattara, 2007) [14]. The taxonomy of the phytoplankton community in the park's reservoirs is dominated by Chlorophyta and Euglenophyta, which are characteristic of environments rich in nutritive salts and organic matter resulting from human activity and natural decomposition of tree trunks, dead leaves and animal excrement. The Sorensen index or similarity coefficient gives values ranging from 0.89 to 0.74. These values mean that the Park's water reservoirs have species that are distributed identically in all the stations.

Table 1: Composition and distribution of phytoplankton taxa sampled in the reservoirs of the Azagny National Park from June 2020 to September 2020

TAXA	ST1	ST2	ST3	ST4
Cyanoprokaryota Anagnostidis komárek				
Cyanophyceae Sachs				
Chroococcales Wettstein and Westerheim				
Chroococcaceae Nails				
Aphanocapsa elachista gs West		*x*		*x*
Aphanocapsa incerta Lemmermann	*x*		*x*	
Chroococcus dispersus (Keissler) Lemmermann	*x*		*x*	
Chrococcus turgidus (kützing) Nägeli		*x*	*x*	
Chroococcus sp.	*x*		*x*	*x*
Coelomoron pusillum (Van goor) Komárek	*x*	*x*		
Merismopedia glauca (Ehrenberg) Nägeli		*x*		
Microcystis aeruginosa (Kützing) Kützing	*x*	*x*		*x*
Microcystis incerta Lemmermann	*x*		*x*	
Nostocales (Borzi) Geitler				
Nostocaceae Dumortier				
Anabaena affinis Lemmermann	*x*		*x*	
Anabaena mucosa Komarkov-legnerova and Eloranta				*x*
Anabaena spiroides Klebahn	*x*	*x*	*x*	*x*
Anabaena sp.	*x*		*x*	
Cylindrospermopsis raciborskii (Woloszynska) seenayya & Subba raju				*x*
Elenkin Oscillator				
Oscillatoriaceae (Gray) Bory of St. Vincent				
Oscillatoria princeps Gomont	*x*	*x*	*x*	*x*
Spirulinaceae				
Spirulina meneghiniana fo. *Fontinalis* schwabe				*x*
Spirulina princeps West & West	*x*		*x*	
Spirulina sp.	*x*		*x*	*x*
Heterokontophyta Van den Hoek *and al.*				
Bacillariophyceae Haeckel				
Schütt power stations				
Aulacoseiraceae Crawford				
Aulacoseira granulata var. *Angustissima* (o. Müller) Simonsen	*x*	*x*	*x*	*x*
Aulacoseira granulata var. *Angustissima* fo. *Spiralis* (o. Müller) Simonsen			*x*	*x*
Stephanodiscaceae Glezer and Makarova				
Cyclotella meneghiniana Kützing	*x*			*x*
Pennales schütt				
Amphipleuraceae Grunow				
Frustulia saxonica Rabenhorst	*x*		*x*	*x*
Frustulia rhomboides (Ehrenberg) De Toni	*x*		*x*	*x*
Frustulia sp.	*x*			
Nitzschia acicularis (Kützing) W.smith	*x*			
Nitzschia amphibia Grunow			*x*	

Nitzschia longissima (Brébisson) Ralfs	*x*		*x*	
Nitzschia perversa Grunow	*x*			
Nitzschia sigma (Kützing) W.smith				*x*
Nitzschia sigmoidea (Nitzsch) W.smith		*x*	*x*	*x*
Achnanthidiaceae dg Mann				
Achnanthidium minutissimum (Kützing) Czarnecki		*x*		
Cocconeidaceae Kützing				
Cocconeis ankobraensis Foged		*x*		
Cocconeis placentula Ehrenberg			*x*	
Diadesmidaceae Mann				
Diadesmis contenta (Grunow) dgMann		*x*	*x*	
Diploneidineae				
Diploneis smithii (Brébisson) Cleve			*x*	*x*
Diploneis sp.			*x*	
Eunotiaceae Kützing				
Eunotia sp.		*x*		
Fragilariaceae Kützing				
Fragilaria acus (Kützing) Lange-bertalot				*x*
Fragilaria crotenensis Kitton	*x*	*x*	*x*	*x*
Fragilaria ulna (Nitzsch) Lange-bertalot	*x*	*x*	*x*	*x*
Gomphonemataceae Kützing				
Gomphonema brasiliense Grunow				*x*
Naviculaceae Kützing				
Gyrosigma acuminatum (Kützing) Rabenhorst	*x*	*x*	*x*	*x*
Gyrosigma attenuatum (Kützing) Rabenhorst	*x*		*x*	
Gyrosigma balticum (Ehrenberg) Rabenhorst			*x*	
Gyrosigma nodiferum (Grunow) Reimer		*x*		
Gyrosigma scalproides (Rabenhorst) Cleve	*x*		*x*	
Gyrosigma sp.				*x*
Navicula gastrum (Ehrenberg) Kützing				*x*
Navicula contenta Grunow in van Heurck			*x*	
Navicula subtilissima Cleve		*x*		
Navicula sp.	*x*		*x*	*x*
Pinnulariaceae Mann *in* Round *et al.*				
Pinnularia acrosphaeria W.smith	*x*	*x*		
Pinnularia brebissonii (Kützing) Rabenhorst				*x*
Pinnularia divergens W. Smith	*x*		*x*	*x*
Pinnularia maior var. *Linearis* Cleve		*x*		
Pinnularia microstauron (Ehrenberg) Cleve				*x*
Pinnularia sp.	*x*	*x*		
Pleurosigmataceae Mereschkowsky				
Pleurosigma diverstriatum F.meister			*x*	*x*
Pleurosigma salinarum (Grunow) Cleve & Grunow			*x*	
Pleurosigma strigosum W. smith			*x*	
Rhopalodiaceae (Karsten) Topachevs'kyj & Oksiyuk				
Epithemia turgida (Ehrenberg) Kützing			*x*	*x*
Epithemia zebra (Ehrenberg) Kützing	*x*		*x*	
Stauroneidaceae Mann				
Stauroneis anceps Ehrenberg	*x*		*x*	
Stauroneis brasiliensis Metzeltin & Lange-bertalot			*x*	*x*
Coscinodiscophyceae Round & Rmcrawford				
Coscidiscals round & rmcrawford				
Coscinodiscaceae Kützing				
Coscinodiscus sp.				*x*
Synurophyceae Cavalier-smith				
Synurales Andersen				
Synuraceae Lemmermann				
Mallomonas matvienkoae (Matvienko) Asmund & Kristiansen	*x*			
CHLOROPHYTA Cavalier-smith				
Chlorophyceae Wille *in* warming				
Sphaeropleales Luerssen				
Ankistrodesmaceae Korshikov				
Ankistrodesmus fusiformis Corda	*x*			
Ankistrodesmus gracillis (Reinsch) Korshikov	*x*			*x*
Chlorococcales Pascher				
Hydrodictyaceae (Gray) Dumortier				
Pediastrum biradiatum Meyen	*x*		*x*	
Pediastrum duplex var. *Gracillimum* West & gs West	*x*	*x*	*x*	*x*

Pediastrum simplex Meyen	x	x	x	
Neochloridaceae Ettl and Komárek				
Tetraëdron incus (Teiling) Gmsmith	x			
Scenedesmaceae Oltmanns				
Crucigeniella rectangularis (Nägeli) Komárek				x
Desmodesmus quadricaudatus (Turpin) Hegewald	x	x	x	
Scenedesmus apiculatus (West & Gswest) Chodat			x	
Scenedesmus acuminatus (Lagerheim) Chodat			x	x
Scenedesmus bernardii Chodat		x	x	
Scenedesmus opoliensis pg Richter			x	
Volvocaceae Ehrenberg				
Eudorina elegans Ehrenberg			x	x
Pandorina morum (Müller) Bory	x		x	
Conjugatophyceae Engler				
Desmidiales Bessey				
Closteriaceae Bessey				
Closterium kuetzingii Brébisson	x		x	x
Closterium lineatum Wolle	x	x		
Desmidiaceae Kützing ex Ralfs				
Cosmarium connatum Brébisson ex Ralfs				x
Cosmarium reniforme (Ralfs) W.archer	x			
Pleurotaenuim eugeneum (w. B. Turner) West & West			x	x
Staurastrum asperatum Behre		x		
Staurastrum Leptocladum Nordstedt	x		x	
Staurastrum tetracerum Ralfs			x	
Staurastrum sp.		x	x	
Staurodesmus convergens (Ralfs) Lillier				
Teilingia granulata (Roy and Bisset) Bourrelly	x			
Mesotaeniaceae Rabenhorst				
Gonatozygon brebissonii De Bary		x	x	x
Zygnemataceae Kützing				
Spirogyra sp.				x
Euglenophyta Pascher				
Euglenophyceae Schoenichen				
Euglenales Engler				
Euglenaceae Stein				
Euglena proxima Dangeard		x		
Euglena spirogyra Ehrenberg		x	x	
Euglena sp.	x	x		x
Lepocinclis acus (Müller) Marin and Melkonian		x		x
Lepocinclis oxyuris (Schmarda) Marin and Melkonian		x		x
Lepocinclis ovum Ehrenberg	x	x	x	x
Lepocinclis salina Fefritsch	x		x	x
Lepocinclis texta (Dujardin) Lemmerman			x	x
Phacus acuminatus A.stokes			x	x
Phacus cuvicauda Svirenko		x		
Phacus indicus Skvortsov			x	
Phacus longicauda (Ehrenberg) Dujardin	x	x		x
Phacus orbicularis Hübner	x	x		
Phacus onyx Pochmann	x	x	x	x
Phacus ranula Pochmann	x			
Phacus suecicus Lemermann		x	x	x
Phacus tortus (Lemermann) Skvortzov	x	x	x	
Strombomonas acuminata (Schmarda) Deflandre	x	x	x	
Strombomonas fluviatilis (Lemmermann) Deflandre			x	
Strombomonas treubii (Wołoszyńska) Deflandre	x	x	x	
Strombomonas verrucosa (Daday) Deflandre	x			
Trachelomonas abrupta Svirenko	x	x	x	x
Trachelomonas armata (Ehrenberg) F.stein		x		x
Trachelomonas bernardinensis Vischer		x		
Trachelomonas curta Amcunha	x	x	x	
Trachelomonas hispida (Perty) Stein	x			x
Trachelomonas lefevrei Deflandre	x	x	x	x
Trachelomonas oblonga Lemmermann	x		x	
Trachelomonas planktonica Svirenko		x		
Trachelomonas radiosa Fritsch	xx	x		x
Trachelomonas scabra Playfair	x		x	
Trachelomonas similis Stokes	x		x	x

Trachelomonas superba Swirenko (Emend.) Deflandre		x		x
Trachelomonas volvocina Ehrenberg	x	x	x	x
Trachelomonas volvocinopsis Swirenko				
Trachelomonas sp. 1	x	x		
Trachelomonas sp.2	x	x		x
Trachelomonas sp.3		x		x
Trachelomonas sp.4		x		x
DINOPHYTA Auct.				
Dinophyceae Pascher				
Haeckel's Peridiniales				
Peridiniaceae Ehrenberg				
Bagredinium crenulatum Da, Zongo, Mascarell and Couté	x		x	
Peridinium sp.	x			
Total: 134	69	56	74	63

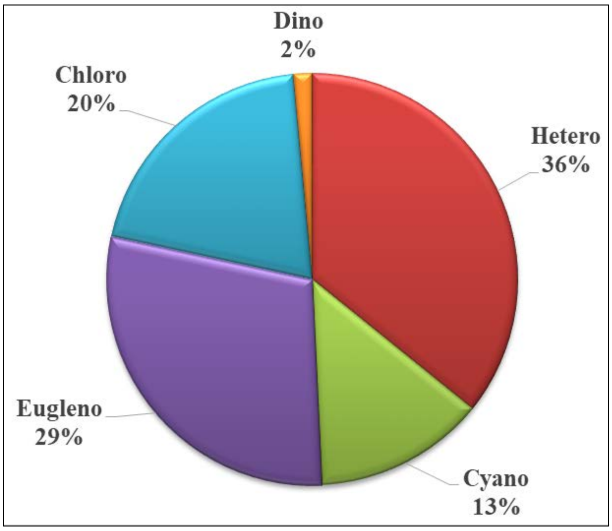

Fig 2: Proportion of the different phyla observed. Chloro: Chlorophyta; Cyano: Cyanoprokaryota; Dino: Dinophyta; Eugleno: Euglenophyta; Hetero: Heterokontophyta

3.3 Trophic status

The values of the A index and the B index, amounting to 9.81 and 1.62 respectively, indicate an eutrophic state of the water in the reservoirs. The C index, with a value of 0.11, indicates an Oligotrophic state. These results enabled us to assess the trophic status of the park's reservoirs, which tends more towards eutrophic conditions. At all the stations, of the three indices calculated, two (index A and index B) give values that show that the park's reservoirs are eutrophic and index C gives values for oligotrophic environments. Based on the values for physico-chemical parameters such as phosphate (0.32 mg/l and 0.47 mg/l), dissolved oxygen (2.00 mg/l and 6.56 mg/l), nitrate (0.18 mg/l and 0.62 mg/l) and transparency (0.07m and 0.48m), the water in the park tends to be eutrophic after comparing these values with those obtained by Mason (1991) [15]. Taking the biological aspect into account, we also note that the waters in the park are closer to the eutrophic state than to the oligotrophic or mesotrophic state. According to Brook (1965) [16], the relative number of species representing different taxonomic groups in a phytoplankton sample reflects the ecological conditions of the environment. Consequently, in eutrophic lakes, the number of species of Chlorococcales would be greater than the number of Desmidiaceae, and the opposite conditions in oligotrophic lakes (Rawson, 1956) [17]. In our study, the same observations were made (more Chlorococcales than Desmidiaceae).

4. Conclusion

This study, carried out in the reservoirs of the Azagny National Park, revealed that 134 phytoplankton taxa were inventoried. Of the five phyla observed, two are more representative in terms of the number of taxa. These were the Heterokontophyta (35.82%) and the Euglenophyta (29.10%). This work has shown that the waters within the Park are negatively impacted by human activities in the surrounding area, on the one hand, and are influenced by natural phenomena such as the decomposition of organic matter, on the other. The physico-chemical parameters and the various indices calculated have enabled us to say that the park's water reservoirs are tending towards a state of eutrophy that is favourable to certain species of toxic cyanobacteria, which could be a danger to the emblematic and rare protected species.

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