Succession of phytoplankton in a municipal waste water treatment system under sunlight

Sucesión del fitoplancton en un medio de tratamiento de aguas provenientes de desechos Municipales utilizando luz solar

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Received: 08/21/2007 First reviewing ending: 10/09/2007 First review received: 10/29/2007
Second reviewing ending: 11/26/2007 Second review received: 12/07/2007 Accepted: 12/13/2007

ABSTRACT

A study on succession of phytoplankton in a municipal waste water treatment was conducted from a major drainage stream system receiving municipal wastes from densely populated urban municipality of Port Harcourt in Rivers State, Niger Delta of Nigeria. The study area lies within 4º 88″ - 4º 99″ N and 5º 00″ - 5º 14″ E. The study was carried out to investigate the variation of phytoplankton communities and their interactions with the physico-chemical characteristics of the waste water being treated with sunlight. The phytoplankton population indicated six (6) major successional development patterns in the recruitment of species. This affected the distribution of phytoplankton descriptors such as species diversity -H' (that decreased from 0.99 on the 1st day to 0.62 on the16th day), dominant index -DI (with minimum of 0.000085 on the 1st day to maximum of 0.12 on the 11th day), community structure and biomass at various stages of the depuration and correlated differently with the physicochemical parameters. The results suggest that phytoplankton was mainly regulated by nutrients and the massive Cyanobacterial bloom declined as the water quality improved which were well related to changes in algae diversity, dominance index, abundance and biomass. A model to compare actual and predicted values indicated some coherence between several biological and physicochemical attributes.

Kew words: Phytoplankton, municipal wastewater, dominant index, Cyanobacteria

RESUMEN

Se condujo un estudio sobre la sucesión del fitoplancton en un tratamiento de aguas residuales Municipales en muestras de un sistema importante de corrientes de drenaje, el cual recibía desechos municipales de un área urbana densamente poblada de Diobu en la Municipalidad de Port Harcourt, Rivers State, Niger Delta de Nigeria. El área de estudio se encuentra entre la longitud 4º 99'' y 4º 88'' N y la latitud 5º 00'' y 5º 14'' Este. El experimento fue realizado para investigar la variación de las comunidades del fitoplancton y su interacción con las características físico-químicas de las aguas residuales las cuales se trataron con luz solar. La población del fitoplancton indicó seis patrones principales de desarrollo sucesional en el reclutamiento de las especies. Esto afectó la distribución de los descriptores del fitoplancton tales como la diversidad de especies -H' (que disminuyó de 0,99 en el primer día a 0,62 en el día 16), el índice de dominancia –ID (con un valor mínimo de 0,000085 en el primer día a un valor máximo de 0,12 en el undécimo día), la estructura de la comunidad y la biomasa en diferentes etapas de la depuración y correlacionó de manera diferente con los atributos físico-químicos. Los resultados sugieren que el fitoplancton estuvo principalmente regulado por los nutrimentos y la floración masiva de la Cianobacteria disminuyó a medida que mejoró la calidad del agua, las cuales estuvieron bien relacionadas con los cambios en la diversidad de las algas, el índice de dominancia, la abundancia y la biomasa. Un modelo para comparar los valores reales y predichos indicó alguna coherencia entre varios atributos biológicos y físico-químicos.

Palabras claves: Fitoplancton, aguas residuales municipales, índice de dominancia, Cianobacteria

INTRODUCTION

The concern on the quantity and quality of waste generated and discharged into natural water bodies has recently indicated the need for different strategies to address water quality challenges in the regions. The municipal areas of Port Harcourt were found to have poor water quality; while water qualities in the outskirts of the cities were considered fair (Ogan, 1988), associated with dense populations, and intense economic activity.

This concern on waste water quality resulted in considering the possible treatment option bearing in mind inexpensive ways of administering wastes in the third world. The wastes generated and discharged are mostly from domestic sources (household facilities, open markets, garages laundry) and small scale industrial set ups (laundry and photographic shops). These wastes are generally discharged into a nearby water body.

The population of the area adjoining the study stream system is high (70.25million) and over 85% of the stream bank is developed with infrastructural facilities such as concrete residential housing units, garages, photographic shops, car wash and market stalls. These adjoining activities from these introduce considerable solid and liquid wastes that impact on the water quality integrity as it receives about 4500 litres/day of waste containing petroleum product especially as crankcase oil and spent oil, over 250,000 litres/day of domestic wastes, human wastes of 120 litres/day, 20kg/day of metal and 58 kg/day of solid waste such as paper, polyethylene bags and cotton materials (Ogamba, 2003).

These wastes generated and discharged contain several chemical components that are organic and inorganic in origin. The impacts of the waste components in altering habitat integrity of natural water bodies have been reported in previous studies (Ajayi and Osibanjo, 1981; Ibiebele *et al*., 1987; Powell, 1987; Ekweozor *et al.*, 1987; Chindah, 1998; Chindah *et al*., 2005). These discharges cause damage to human health, fisheries, and agriculture, and results in associated health and economic costs (Okpokwasili and Nwabuzor, 1988; IPS, 1990; Okpokwasili and Olisa, 1991; Joiris and Azokwu, 1999; Chindah and Sibeudu, 2003, Ndiokwere, 1984). It also threatens ecosystems through eutrophication, and is responsible for the loss of plant and animal species. Improving the surface water quality and sanitation will substantially reduce the incidence and severity of water borne associated diseases in the area. In developing nations the challenges of handling and treating waste water has been difficult to due to the unaffordable financial implication for government to undertake. It is for this reason that research effort was made to adopt an inexpensive procedure (exposing waste water under solar radiation) that indicated a measurable success in the physicochemical quality (Chindah *et al*., 2005). Understanding of the dynamics of the biological organism particularly the primary producer in the treatment system is considered important as information in this respect is lacking. On the basis of existing gap in knowledge this study was undertaken to evaluate the response of phytoplankton to the treatment process of municipal wastes.

MATERIALS AND METHODS

Site description

The study area has the characteristic feature of tropical equatorial latitude with high humid and temperature which is more or less uniform all through the year. Rainfall occurs almost all the months (May - November) of the year with short duration of dry season (December - April). The annual average rainfall is 2360mm (Gobo, 1988) and humidity is generally high for both wet and dry season (> 85%). The natural drainage basin is largely exposed as vegetation is virtually removed by adjacent development and macrophytes such as *Nymphaea micrantha, N. lotus, Pistia stratiotes, Ludwigia leptocarpa*, *Ipomea aquatica*, *Neptuna oleracea*, *Cyperus distans,* are the only plants that occupy the outer margin of the drainage system.

Sampling

Samples for the study were collected from a major drainage basin receiving municipal wastes from densely populated urban area of Diobu in Port Harcourt municipality. The area lies within 4^o 99” - 4^o 88” N and 5^o 00” - 5^o 14” E (Figure 1). Based on previous studies, samples were collected in February 2000, from the study location and placed in 3 black body tanks (200L capacity) and transferred to the Institute of Pollution Studies Laboratory for daily analysis for 16 days for all parameters (Chindah *et al*., 2005).

Physicochemical parameters

Samples were collected in one litre plastic containers at sub-surface level and analyzed in the Institute of Pollution Studies (IPS) laboratory using procedures as outlined in standard method for the examination of water and waste water (APHA, 1998). The following parameters were investigated: temperature, pH, conductivity, alkalinity Dissolved oxygen (DO), Biochemical oxygen demand (BOD_5), ammonia-nitrogen, nitrate-nitrogen, sulphate, phosphate. Temperature was measurement in-situ using mercury in bulb thermometer. pH, conductivity, turbidity total dissolved solids (TDS) were measured using multiprobe Horiba instrument (water checker model U-10). Dissolved oxygen (DO) and Biochemical oxygen demand (BOD_5) were determined using Winkler's method (APHA,1998). Total suspended solids and Nutrient parameters (nitrate (NO_3^-), ammonia (NH_3^-), phosphate (PO_4^{-3}), sulphate (SO_4^{-2}) were determine using the spectrophotometric method (spectronic instrument 21D) at various wavelengths based on Standard methods for the determination of water and wastewater as stated in APHA (1998).

Qualitative and quantitative analysis of Phytoplankton

Phytoplankton and chlorophyll 'a' samples were collected each day in triplicate with 50ml and 20 ml bottles respectively. The 50ml sample was immediately fixed with Lugol's solution, allowed to settle for 24hrs before decanting to a uniform concentration (10ml). The samples were properly homogenized and 1ml sub-sample from original stock was collected with a sample pipette for numerical analysis. The pipette content was transferred into a Sedgewick - Rafter counting chamber for

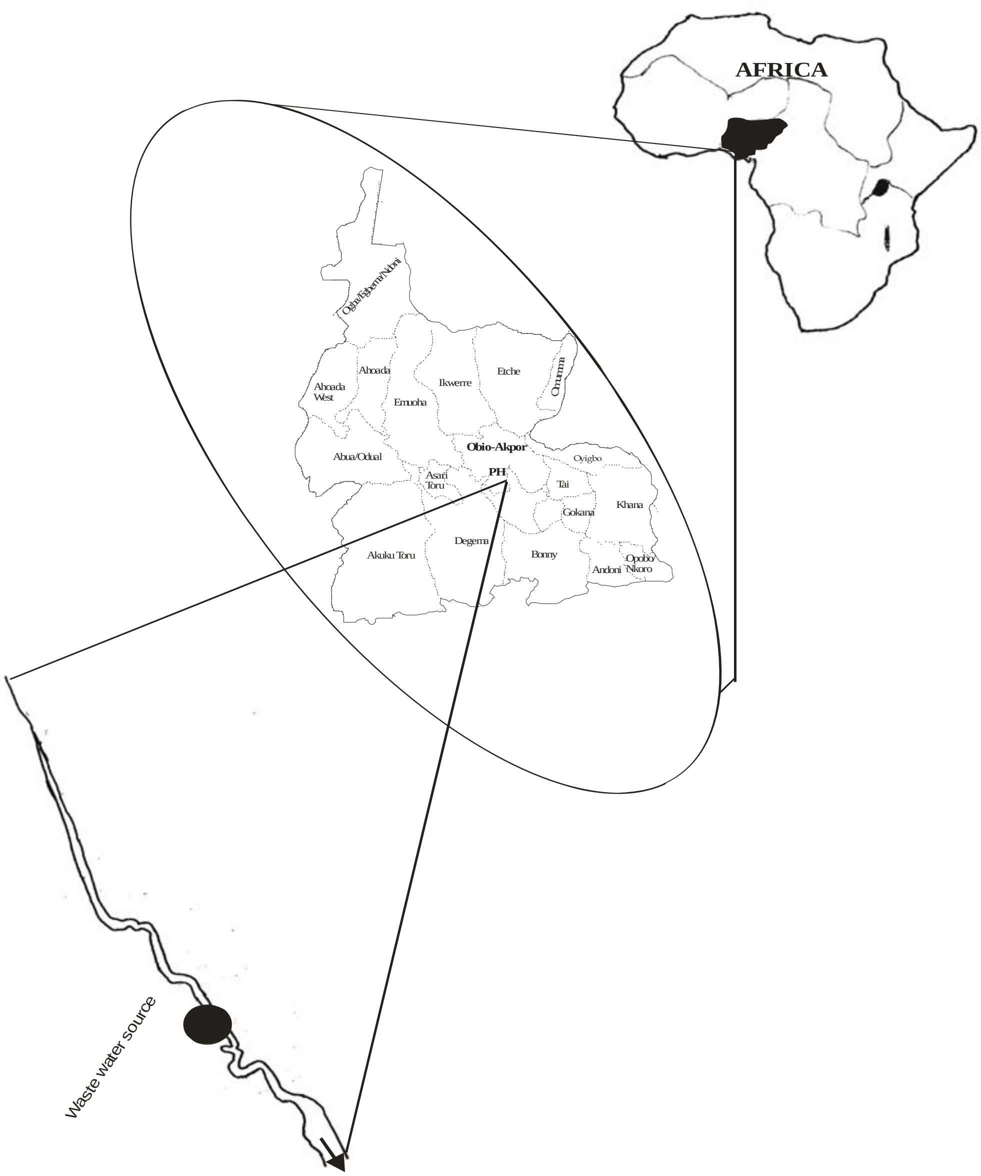

Figure 1. The Map of Nigeria, Rivers State, showing the wastewater source.

enumeration using a Lietz binocular microscope magnification of 200x and identification of 1000x using the reports of Mills (1932), Sieminska (1964), Starmach (1966), Patrick and Reimer (1966) Durand and Leveque (1980) and Chindah and Pudo (1991).

Samples for chlorophyll "a" were analyzed using the trichromatic method as stated in APHA (1998). Twenty ml samples were filtered through a Whatman membrane filter (0.45µm) and immediately placed in a vial containing 90% acetone wrapped with foil for chlorophyll "a" analysis. The filtrate was ground, centrifuged and the supernatant and blank (acetone) were determined at 663nm and 665nm wavelength using Spectronic 21D and values obtained calculated for chlorophyll 'a' as indicated in APHA (1998).

Statistical analysis

The Shannon –Weaver, species diversity index, H′ (Margalef, 1958) was used:

$$H' = - \sum ni / N \log_2 ni / N$$

Where ni is the number of species in group (i), N is the total number of individuals in (i) group.

Dominance index
The dominance index was calculated using the Bergen-Parker dominance index (Chellappa 1990):

D = n max/NT

Where: n max = number of individuals of the dominant species.

NT = total number of individuals of all the species recorded

The two indices, relationships between physico-chemical and phytoplankton variables were estimated by simple linear correlation and regression model analyses performed with Microsoft Excel 2003.

RESULTS

Physicochemical parameters

The physicochemical changes observed during the treatment process have been reported earlier Chindah *et al*., (2005) with the synopsis on the recovery presented in Table 1.

Phytoplankton

Species occurrence and successional patterns

A total of 50 phytoplankton species were observed during the study and the taxa representing four major algal groups (Bacillariophyceae, Chlorophyceae, Cyanophyceae, and Euglenophyceae) are contained in Table 2.

Phytoplankton species demonstrated variation in occurrence at different times during the treatment process. It was observed that initial resident species in the phytoplankton community in the municipal waste water is *Merismopedia punctata*, *Anacystis aeuroginosa*, and *Romeria elegans*, with the debut emergence of new organisms few days after (*Lyngbya*

Table 1. Physicochemical variables in the wastewater treatment system from Diobu in Port Harcourt , Nigeria.

S/no parameter	Range	Mean and SD	% recovery
Temperature (ºC)	26.5 - 32	29.24 ± 2.16	ND
pH	7.2 – 9.0	7.91 ± 0.50	80,00*
Conductivity (µScm^{-1})	506 - 706	620.87 ± 70.26	72.94
Turbidity (NTU)	3 - 62 ± 22.66	22.67 ± 13.36	95.20
TDS (mg/l)	358 - 494	440.2 ± 45.81	27.10
TSS (mg/l)	1.74 - 3.19	2.746 ± 0.52	45.50
DO (mg/l)	0.23 -6	2.01 ± 2.15	96.00
BOD_5 (mg/l)	0.92 - 28.5	16.25 ±11.86	96.80
COD (mg/l)	0.81 - 19.95	11.38 ± 8.31	96.80
Nitrate (mg/l)	0.04 - 0.64	0.22 ± 0.16	93.75
Phosphate (mg/l)	0.39 - 4.54	2.83 ± 1.36	91.40
Sulphate (mg/l)	8.81 - 16.01	12.46 ±2.82	45.90

ND – not determined, * increased value

pseudospirulina, Anabaenopsis arnoldis, Gomphosphaeria sp., *Ulothrix limeatica* Lemmru, while other entrants into the community appear towards the end of the study (*Oscillatoria terebriformis, Gloeocapsa maya, Scenedesmus obligues*) (Figure 2).

During the emergence of the species two main characteristic attributes were observed, firstly were species that erupted and quickly created an outburst in population (*Anabaena flos-aquae, Phormidium acumulatus,* and *Navicula minima*), and secondly those that made appearances with negligible impact on the population density (*Rhabdoderma lineare,* and *Romeria elegans*).

Another feature observed amongst the species were on status of their residents in the community, with some species being permanent residence (*Anacystis aeuroginosa*) and transitory species that had two suites such as *Euglena pascherii, Phormidium acumulatus, Achnanthes lanceolata, Navicula minima,* and *Synedra acus* that occurred earlier during the treatment process and *Scenedesmus acornis, Scenedesmus quadricauda* and *Nitzschia linearis* that were observed almost towards the end of the treatment process (Figure 2).

These two prominent scenarios gave rise to six major successional patterns observed; firstly was within the 2^{nd} day of the experiment when *Oscillatoria terebriformis, Merismopedia punctata, Romeria elegans, Anacystis aeuroginosa,* and *Chroococcus species* were observed in the community.

Table 2. Identified phytoplankton species and their occurrence in the treatment from urban area of Diobu in Port Harcourt Municipality, Rivers State, Niger Delta of Nigeria.

Cyanophyceae
Chrococcus minuta Skuja
Chrococcus turgidus Nag.
Chroococcus sp.
Oscillatoria terebriformis Gomont
Oscillatoria sp.
Merismopedia punctata Meyer
Lygbya pseudospirulina (Utermorhl)Pascher
Rhabdoderma lineare Schm. Lauter.
Romeria elegans (Wolosz.) Kocz.
Anacystis aeruginosa Kutz.
Anabaenopsis arnoldis Aptekarj
Anabaena flos-aquae (Lyng.) Breb
Gomphosphaeria sp.
Gloeocapsa magma (Breb) Hullerb.

Chlorophyceae
Chlamydomonas spp.
Chloromonas ulla (Skuja) Gerloff et Ettl.
Phacotus laticularis(Ehrenberg) Stein
Euastropsis richter (Schmidle) Lagerheim.
Coelastella levicostata Chodat
Tetradesmus crocici Fott et Kom
Scenedesmus quadricauda (Turpin) Brébisson
Euastropsis spp.
Scenedesmus ecornis (Ehr.)
Scenedesmus ovalternus (Bernard) Chodat
Scenedesmus obliguues (Breb.) Playfair

Chlorophyceae
Scenedesmus pseudodenticulatus Hegewald
Ulothrix limeatica Lemru
Roya cambria W.west & G.E.West
Closterium limneticum Ehr.
Cosmarium pyramidatum Breb.
Staurastrum apiculatum Breb

Euglenophyceae
Euglena acus Ehr.
Euglena pascherii Swirenko
*Lepocinclis teres ((*Schm.tz) Fr.
Lepocinclis stenii Lemm.
Phacus granum Drezepolski
Phacus acuminatus Stokes
Phacus pleuronectes (Ehr.) Duj.
Trachelomonas zuberi Koczwara

Bacillariophyceae
Achnanthes lanceolata (Breb.) Grun.
Achnanthes linearis (W.Sm.) Grun.
Fragilaria crotonensis Kitt.
Navicula cuspidata Kutz.
Navicula minuscula Grun.
Navicula minima Grun.
Navicula laterostrata Hust.
Gomphonema spp.
Synedra acus Kutz.
Nitzschia linearis W.Sm. Grun.
Pinnularia maior (Kutz) Cl.

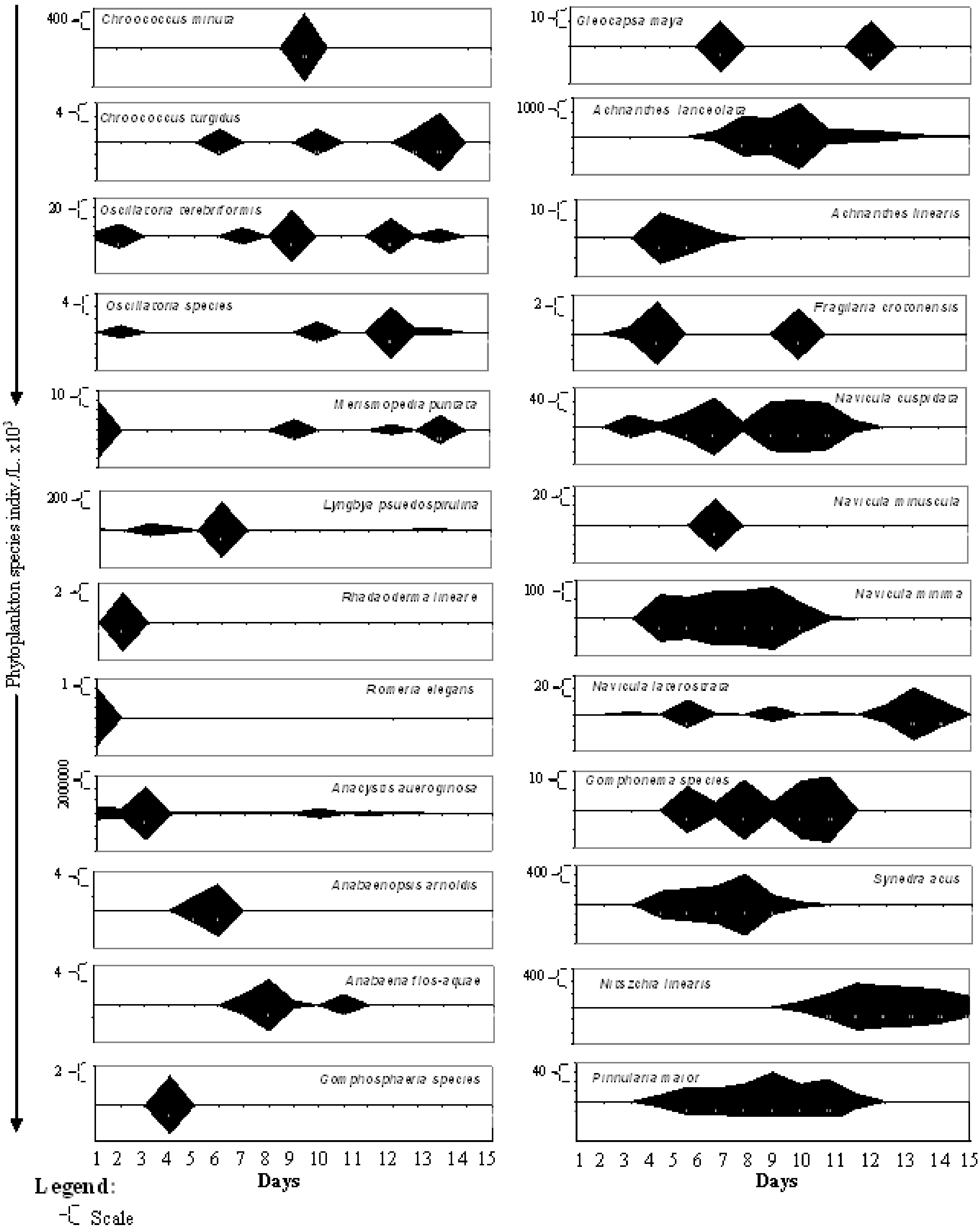

Figure 2. The succession of phytoplankton species in the wastewater treatment

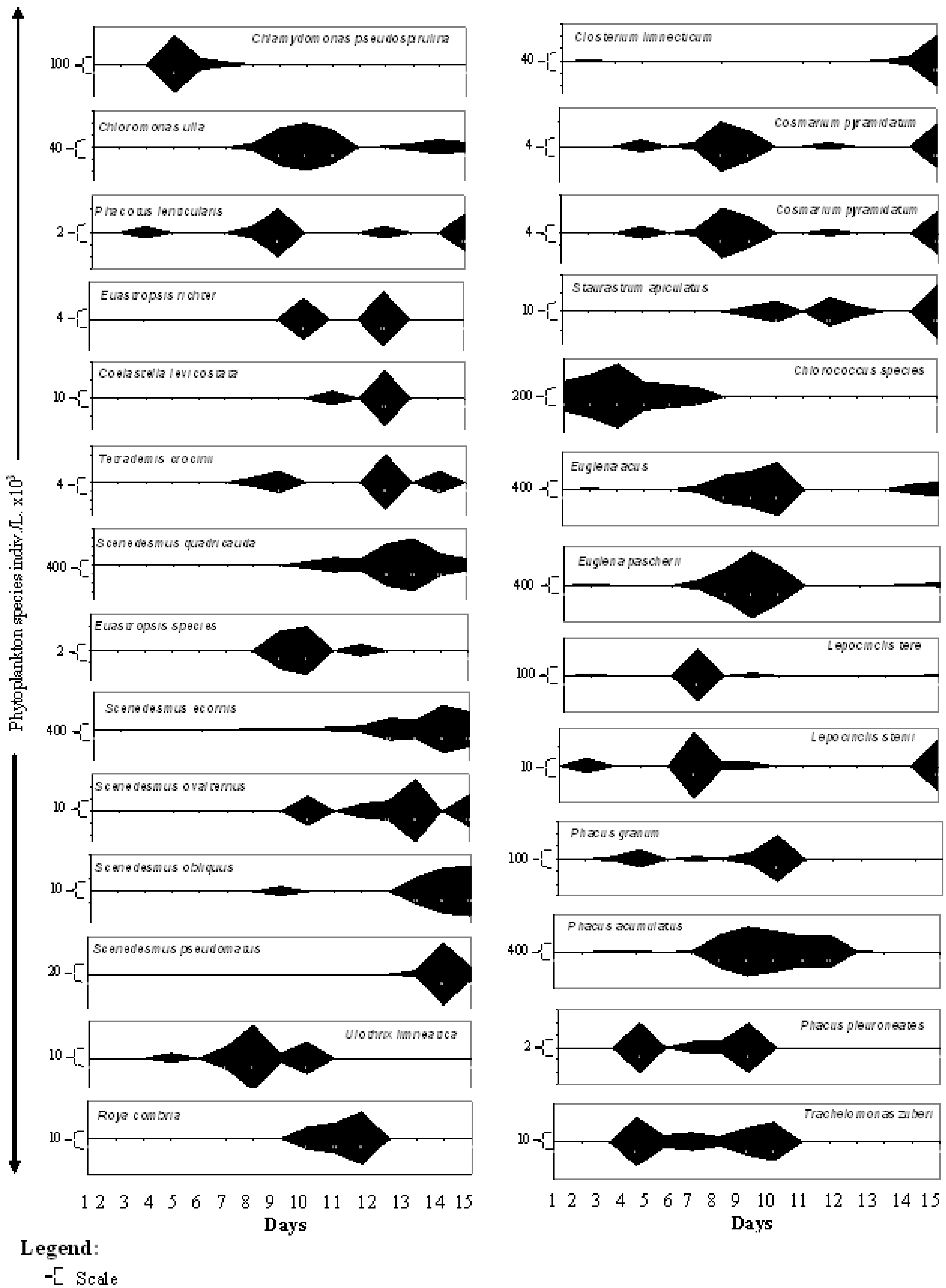

Figure 2cont: The succession of phytoplankton species in the wastewater treatment.

The second pattern was observed a few days later (day 2 - day 4) with species such as *Lepocinclis stenii, Oscillatoria* spp., *Rhabdoderma lineare, Lyngbya pseudospirulina, Closterium limneticum, Navicula laterostrata, Navicula cuspidata, Euastropsis richter, Phacotus lendneris, Euglena acus, E. pascherii, Lepocinclis teres* (schm), and *Synedra acus* predominated the phytoplankton community. The third was observed towards the first half (day 5 and day 6) with 13 other species emerging and contributing to the phytoplankton population (*Anabaenopsis arnoldis, Gomphosphaeria* sp., *Chlamydomonas* sp., *Ulothrix limeatica, Cosmarium pyramidatum, Fragilaria crotonensis, Phacus pleuroneates, Trachelomonas zuberi, Navicula minima, Gomphonema* sp., *Pinnularia maior, Phacus granum,* and *Achnathes lanceolata*).

The fourth successsional pattern occurred midway to the end of the study (7 – 8th day) with 10 species (*Chroococcus turgdus, Anabaena flos-aquae, Gloeocapsa magma, Chloromonas ulla, Tetradesmus crocinii, Scenedesmus acornis, Staurastrum apicultus, Scenedesmus obligues, Navicula minuscula, Phacus acumulatus*) (Figure 2).

The fifth was observed close to the ending of the study (9 – 10th day) with 8 species (*Chroococcus minuta, Euastropsis richter, Scenedesmus quadricauda, Euastropis richerii, Coelastrella levicostata, Scenedesmus ovalternus, Roya cambria, Nitzschia linearis*).

The sixth pattern was the predominance of *Scenedesmus pseudodenticulatus* almost at the end of the experiment (Figure 2).

The community structure initially exhibited preponderance of Cyanophyceae (blue-green algae) for the first 8 days of exposure (1- 8 days) thereafter decreased considerably; except on the 10th day and 12th day, when sudden increase was observed. Other groups in the phytoplankton community resurgence in proportion over time include, Euglenophyceae, the first to quickly attain a relatively high importance in the community - 25.6% (day 7) (Figure 3). The concentration increased to a maximum of 47.1% two days after (day 9) and declined somewhat till the end of the experiment. To the contrary, Chlorophyceae increased almost steadily (exponentially) to attain maximum importance in the community at the end of the experiment (15th day). Similarly, maximum importance by Bacillariophyceae was equally observed in the community toward the end of the experiment (day 13).

The species diversity during the depuration process rapidly cascaded from start to end of the study as maximum species diversity was observed at day 1(H' = 0.99), diversity values were maintained till

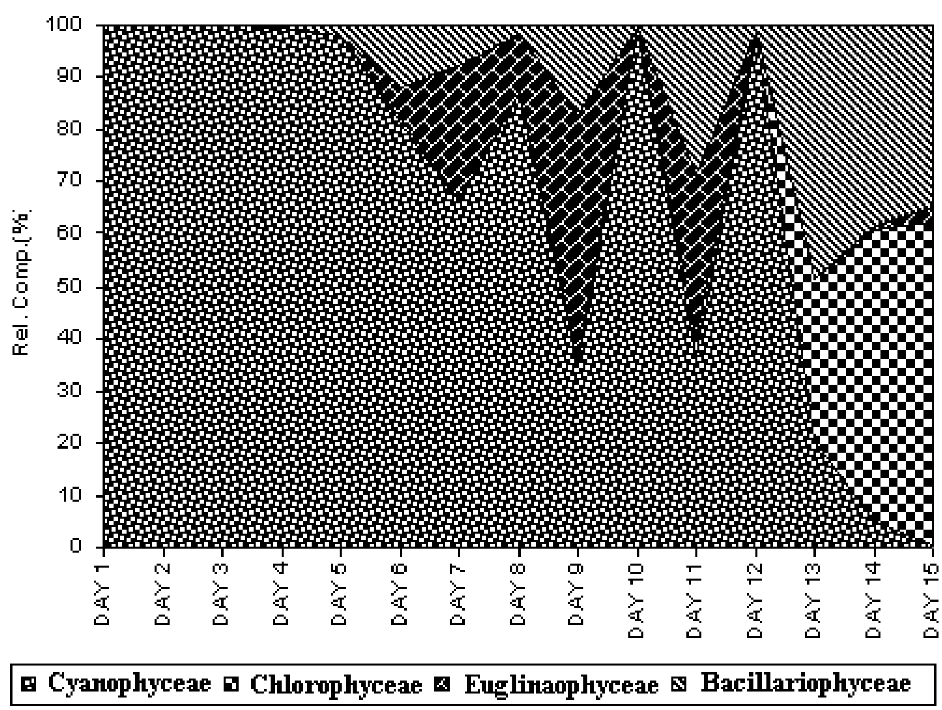

Figure 3. The community structure phytoplankton species in the wastewater treatment

the 4th day (H' = 0.99) before declining steadily to day 7 (0.66) thereafter values oscillated to the end of the experiment (H' = 0.62), however, the minimum species diversity was on the 11th day of exposure (Figure 4).

Conversely, the dominant index had maximum value of 0.12 on the 11th day of the exposure period and the minimum on the first day (0.000085) demonstrating an inverse relationship with species diversity (Figure 4).

Similarly, the phytoplankton densities oscillated over time. The maximum density occurred at day 1, and then declined to an initial low of 12700 $x10^3$ indiv./L at day 6. Thereafter, densities oscillated widely but with a somewhat declining consistently to a minimum of 9303 $x10^3$ individuals/L at day 15 (Figure 5).

The biomass values for chlorophyll 'a' fluctuated widely (irregularly) from day 1(59.51mg/m^3) to day 12(47.75mg/m^3). On day 13, the biomass values increased sharply (613.29mg/m^3) and then declined on day 15 (542.33mg/m^3) such that the chlorophyll 'a' levels in the wastewater increased greatly from day 1 to the end with percentage increase from 15 - 89.0% (Figure 5).

The different water quality attributes and phytoplankton descriptors during the exposure period (t), were compared and the trend demonstrated series of relationship such as the high positive correlation between pH and species diversity (r^2 = 0.59), and chlorophyll 'a' (0.69), Dominant index and TDS (r^2 = 0.63), Dominant index and conductivity (r^2 = 0.54), Dominant index and nitrate (r^2 = 0.62), Dominant index and abundance (r^2 = 0.62), nitrate and log transformed (log x+1) phytoplankton abundance (r^2 = 0.85). Other positive relationships were observed between dissolved oxygen and species diversity (r^2 = 0.59) and chlorophyll 'a' (r^2 = 0.69), temperature and dominant index (r^2 = 0.50), and species diversity and chlorophyll a (r^2 = 0.59) (Figure 6).

Negative relationships also emerged in the pairing of attributes such as the relationship between chlorophyll and conductivity (r^2 = -0.72), TDS (r^2 = -087), phosphate (r^2 = -0.80), nitrate (r^2 = -0.57), SO_4^{-2} (r^2 = -0.62), dominance (r^2 = -0.67), dominance and species diversity (r^2 = -0.98), pH(r^2 = -0.68), DO(r^2 = -0.64); and species richness and TDS (r^2 = -0.54), and nitrate (r^2 = -0.63) (Figure 6).

In the suite of phytoplankton descriptors, regression dominant index (r^2 = 0.53) had the most significant relationships between the actual and the predicted, followed by chlorophyll a' (r^2 = 0.48, species diversity (r^2 = 0.47), and phytoplankton abundance (r^2 =0.38) (Figure 7 (a-d)).

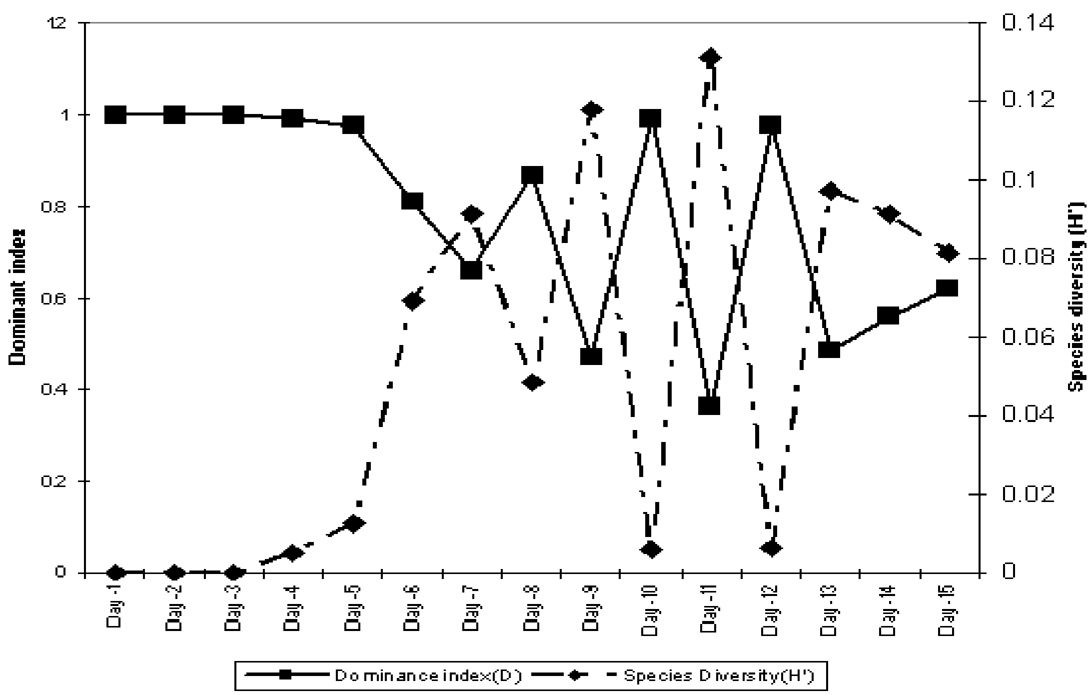

Figure 4. The phytoplankton species diversity index and Dominant index in the wastewater treatment

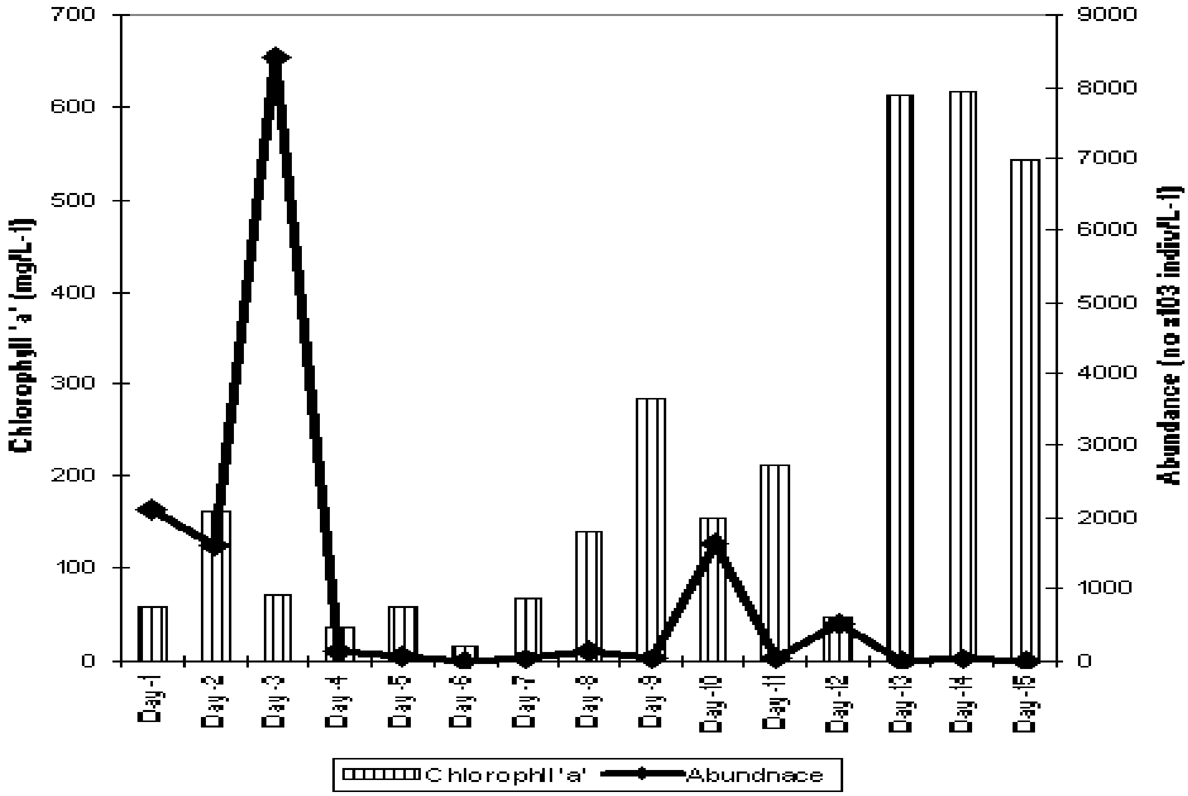

Figure 5. The phytoplankton density and Chlorophyll ‘a’ in the wastewater treatment

Variables	Temperature	pH	TDS	Conductivity	BOD	COD	Nitrate	Sulphate	phosphate	DO	Abundance	Specie diversity	Dominance index	Chlorophyll ‘a’
Abundance	ns	ns	ns	ns	ns	ns	positively significant	ns	ns	ns	ns	ns	ns	ns
Species diversity	ns	positively significant	negatively significant	ns	ns	ns	negatively significant	ns	ns	positively significant	ns	ns	negatively significant	positively significant
Dominance	positively significant	negatively significant	positively significant	positively significant	ns	ns	positively significant	ns	ns	negatively significant	positively significant	negatively significant	ns	ns
Chlorophyll ‘a’	ns	positively significant	negatively significant	negatively significant	ns	ns	negatively significant	negatively significant	ns	positively significant	ns	ns	negatively significant	ns

positively significant
negatively significant
ns not significant

Figure 6. Inter-relationship between physicochemical and phytoplankton descriptors

Also, an attempt was made to find out the model that would adequately correlate the experimental data that could be used for easy prediction and efficient future studies in the field. The regression model was used to predict the responses between dependent and independent variables, which gave rise to the following relationships such as the relationship between species diversity and chlorophyll ‘a’ being represented as species diversity = 0.024 + 0.00013 (chlorophyll ‘a’), where r^2 = 0.320, n = 15 (Figure 8a). Also, dominance index and chlorophyll ‘a’ is represented as dominance index = 0.9360 – 0.000734 (chlorophyll a), where r^2 = 0.4458, n = 15 (Figure 8b).

The relationship between chlorophyll ‘a’ and COD as Chlorophyll a = 297.74 – 8.12 (COD), where r^2 = 0.10, n = 15 (Figure 8c). Chlorophyll ‘a’ and DO is represented as Chlorophyll ‘a’ = 91.21 + 56.76, (DO) where r^2 = 0.32, n = 15 (Figure 8d).

Chlorophyll ‘a’ and BOD_5 is represented as Chlorophyll ‘a’ = 297.77 – 5.68 (BOD_5), where r^2 = 0.10, n = 15 (Figure 8e). Chlorophyll ‘a’ and PO_4^{-3} is represented as Chlorophyll ‘a’ = 561.86 – 125.696 (PO_4^{-3}), where r^2 = 0.649, n = 15 (Figure 8f).

In addition, the multiple linear regression between variables such as chlorophyll ‘a’, BOD_5, DO, and pH is defined by the linear equation: Chlorophyll a = -2201 + 6.49 (BOD_5) + 41.28 (DO) + 280.28 (pH), where r^2 = 0.5815, n = 15.

From the above equation the chlorophyll a concentration in the wastewater increases by the factors 6.49 per unit BOD_5 in the water, 41.28 per unit increase in DO and 280.28 per unit increase in pH. These variables (BOD_5, DO and pH) contribute to chlorophyll a variation in the wastewater. However, only 58% of the changes in chlorophyll a values can be attributed to the BOD_5, DO and pH values based on the coefficient of determination, r^2.

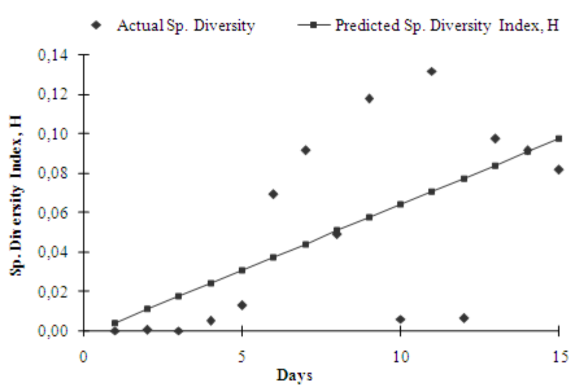

Figure 7a. Regression model for Species Diversity

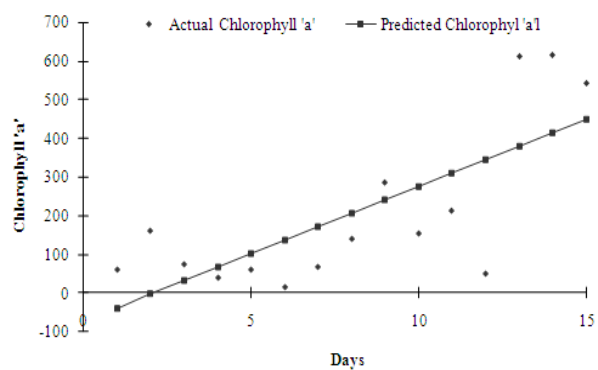

Figure 7c. Regression model for Chlorophyll ‘a’

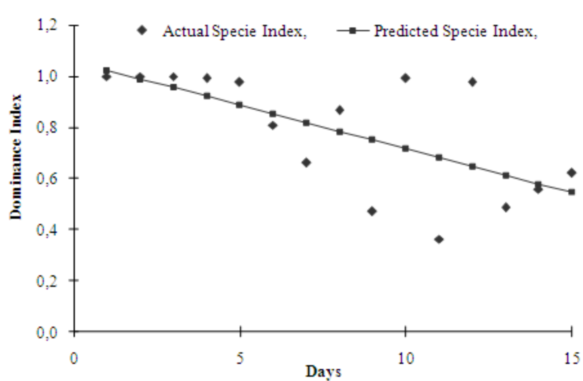

Figure 7b. Regression model for Dominance Index

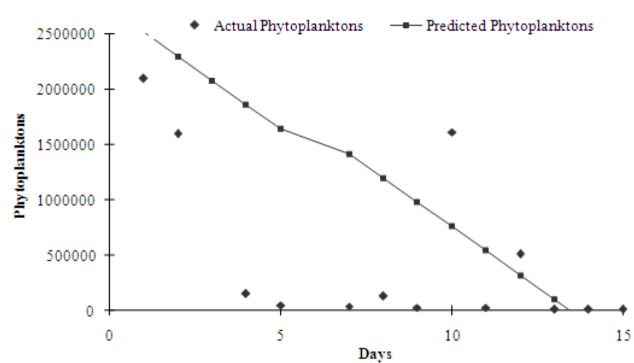

Figure 7d. Regression model for Phytoplankton abundance

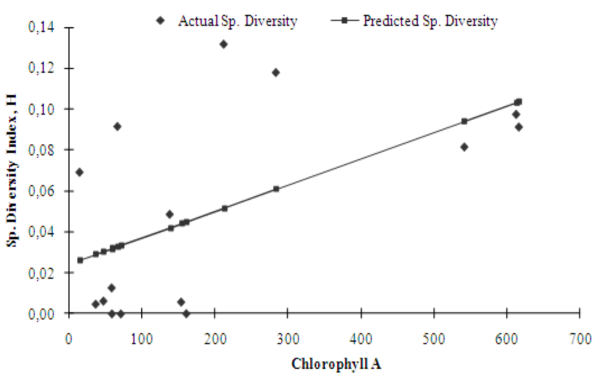

Figure 8a. Relationship between Chlorophyll ‘a’ concentration and species diversity.

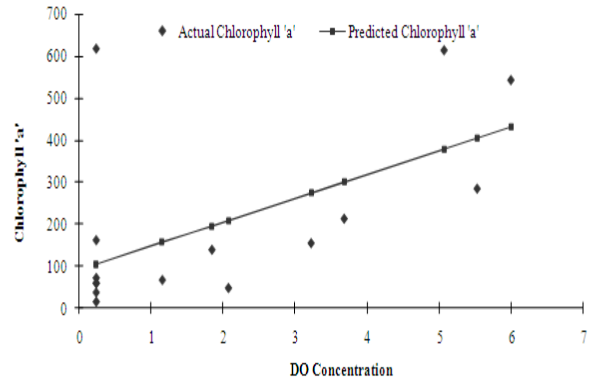

Figure 8d. Relationship between Chlorophyll ‘a’ and DO concentration in the wastewater during the studv

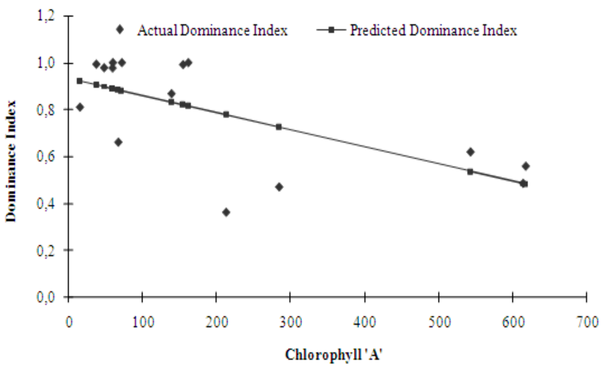

Figure 8b: Relationship between Chlorophyll ‘a’ concentration and species dominance index

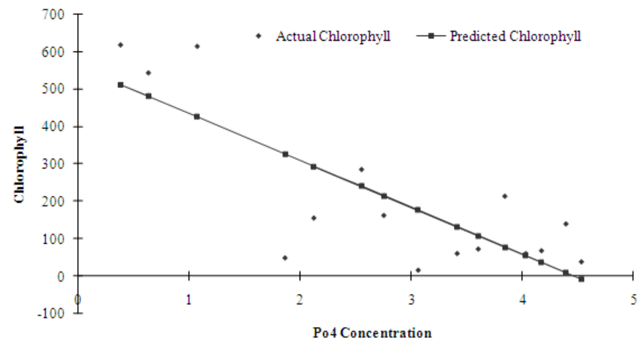

Figure 8e. Relationship between Chlorophyll ‘a’ and PO_4^{-3} concentration in the wastewater during the study.

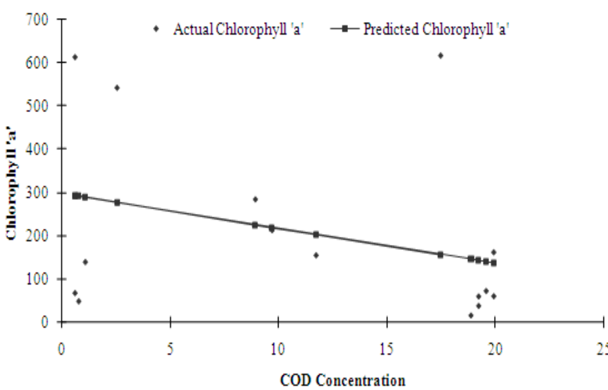

Figure 8c. Relationship between Chlorophyll ‘a’ and COD concentration in the wastewater during the study.

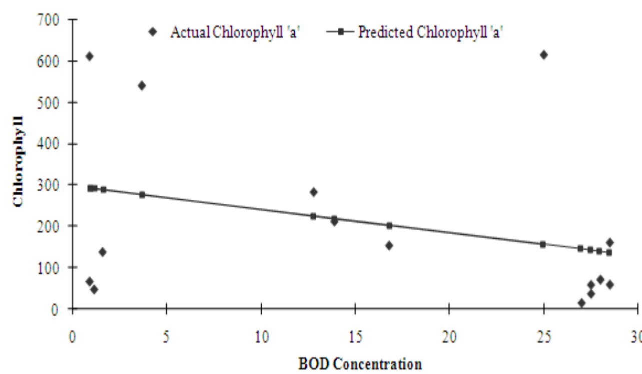

Figure 8f. Relationship between Chlorophyll ‘a’ and BOD_5 concentration in the wastewater during the study

Similarly, the relationship between chlorophyll 'a', and other biological variables (dominance index, species diversity and abundance) in the wastewater is defined by Chlorophyll 'a' = 2592.05 - 2429.66 (dominance index) - 9225.48 (species diversity) - 0.000012 (abundance), where r^2 = 0.6255, n = 15. The level of chlorophyll 'a' in the wastewater decreased by the factors - 2429.66, - 9225.48 and - 0.000012 per unit decrease in dominance index, species diversity and abundance respectively in the wastewater. Only 62.7% of changes in chlorophyll 'a' can be attributed to dominance index, species diversity and abundance of phytoplankton community based on the coefficient of determination r^2. However, the chlorophyll a concentration might be partly attributed to dominance index, species diversity and abundance.

Finally, the relationship between chlorophyll 'a' and nutrient related variables (NO_3^-, PO_4^{3-} and $SO_4^{2-)}$ is defined by the linear equation:

Chlorophyll 'a' = 608.8 – 344.53 (NO_3^-) - 104.78 (PO_4^{3-} - 2.187(SO_4^{2-}), where r^2 = 0.714, n = 15. The chlorophyll 'a' concentration in the wastewater increased by the factors - 344.53, - 104.78, and 2.187 per unit decreases in NO^{3-}, PO_4^{3-} and SO_4^{2-} respectively. The chlorophyll a concentration is partly dependent on the NO_3^-, PO_4^{3-} and SO_4^{2-} concentrations in the wastewater. About 71.4% of the changes in chlorophyll *a* can be attributed to NO_3^-, PO_4^{3-} and SO_4^{2-} based on the coefficient of determination r^2.

DISCUSSION

Recently, research efforts by ecologists are geared towards preventing and solving environmental problems especially those related to human interference such as domestic and industrial wastes that are discharged into the natural environment. Part of these processes is in the domain of ecological management and restoration, predominantly on waste management, to restore habitat integrity through sustainable restoration principles and practice procedures. Understanding the intricate progression of the physicochemical and biological processes in a wastes treatment system is imperative to more efficient management processes. In this respect, this study evaluated biological development in a natural treatment system utilizing solar radiation as energy source. (Berna *et al*., 1986)

Thus the early stages of this study demonstrated low phytoplankton species richness and high abundance against higher species richness and relatively depressed abundance at the later stages that is posited to be associated with the preponderance of few blue green species in the population that have competitive ability to out competed and exterminate the other less tolerant species in the community on account of its ability to produce extracellular substances that are capable of inhibiting the survival and development of other phytoplankton species. Thus the less resistant species that were unable to withstand the stress or unfavourable conditions were eliminated (Chindah, 1998). This implies that the few but dominant species (*Merismopedia punctata, Anacystis aeuroginosa, Romeria elegans*) found in the population at the early stages were species that have competitive ability and/or resilience taxa, competent of producing extracellular substance that inhibited and or eliminated other algal species. These species that can be referred as resistant species, could serve as bio- indicators for municipal waste for the eco-region (Fogg, 1962). Javanmardian and Palsson (1992) had reported similar inhibitory effects of some of these blue green algal species at high density from municipal wastewater. Darley (1982) posited that such inhibitory effect may as well be attributed to reduction in photosynthetic efficiency, self shading and accumulation of auto-inhibitors, since transparency is usually affected by the phytoplankton density and nonliving suspended matter. This contention may result in the reduction of the amount of light impinging and reaching the phytoplankton for photosynthesis (Abdel-Aziz *et al.*, 2001). The scenario may be responsible for the few species richness observed at the early stages when the blue green algal density was high in the treatment waste water (Dorgham *et al*., 2004).

Analogous to this, is the successional pattern observed with the attendant progression in the recruitment of species as the condition of water quality improved especially as nutrient load declined. The sequence of entrants of species into the population by new colonist and or the reemergence of species inadvertently is responsible for the increased species richness and dominance of particular individuals which is similar to the observation reported on nutrient enrich system comparable to wastewater (Hillebrand and Sommer, 1997, 2000; Vymazal, 1988). This circumstances displayed in the emergence of species is an indication of the species preference for a particular water quality to thrive.

These attributes may be answerable to the changes observed in the community structure (from a single Cyanophyceae community at the start of the experiment to a more complex Bacillariophyceae, Chlorophyceae and Euglenophyceae at the termination of the study) is another substantiation that the Cyanophyceae species observed were opportunistic in nature (Chindah, 1998). It is therefore palpable that the occurrence and ascendancy of Bacillariophyceae and the emergence of other taxonomic groups in the phytoplankton community is adjudged as a clear indication of the recovery status of the water quality (Chindah *et al*., 2005).

In contrast to the results of similar studies on waste water in Europe -Spain where *Chlamydomonas* sp. was the dominant taxa (Soler *et al*., 1991), *Anacystis aeuroginosa* was observed as the dominant species. The variability in dominant species in the wastewater type may be associated with the nature and characteristics of the waste water as it appeared that the effluent quality visibly influenced the kind of phytoplankton species. Some of these phytoplankton species observed in this study have been implicated in organic waste polluted environment (Amadi *et al*., 1997). Interestingly, these sequences of events seem to have remarkable effect on the species diversity and dominant index of the phytoplankton species as increase in diversity was observed at the early successional stages but the arrival of new colonist and perhaps competition accounted for the decreased diversity at the later successional stage.

These marked changes observed in this study point to the important role of competitive displacement on temporal species assemblage and occupancy in the wastewater system with adjustment in the physicochemical quality status or as recovery period progresses and to a large extent explains the critical requirement of phytoplankton environment as it tended to improve as equilibrium in the water parameters is achieved.

This is attributed to the reduction of the inhibitory substances which was not determined in this study and improvement of the water quality attributes (Vymazal, 1988; Javanmardian and Palsson, 1992) and perhaps the influence or effect of other parameters such as temperature, solar energy and increased oxygen concentration (Berna *et al*., 1986).

The critical associations observed between the independent and dependable variables highlight the importance of water quality and environmental gradient on the organization of biological resources and the close relationship between the predicted and actual data implies that these parameters can be relied upon in waste water treatment monitoring as it provide understanding of the possible ecologic effects of anthropogenic activities and ecosystem stability. It is the believe of the authors that the study provided a framework in which ecological processes can be manipulated to achieve a desired phytoplankton community that identifies successional activities and dynamic factors influencing succession in a restoring singularly applied treatments

ACKNOWLEDGEMENTS

We wish to thank the staff of the Institute of Pollution Studies (IPS) Rivers State University of Science and Technology, Port Harcourt especially U. J. Ikoro, Hanson Uyi, Nathan Nario and Uchenna Anireh for their support and assistance during the laboratory studies. The authors also acknowledge with thanks the constructive, thorough, and valuable comments by eight anonymous reviewers of this manuscript.

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