

COMPARATIVE ASSESSMENT OF TWO INLAND WATER BODIES IN BAYELSA STATE, NIGERIA

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ABSTRACT

Igbeba-Ago and OxBow Lakes are two inland water bodies in Bayelsa State, Nigeria. The water temperature, dissolved oxygen, pH, salinity, total dissolved solids and turbidity; nitrate and phosphate levels; plankton composition, abundance and diversity indices were evaluated, to provide comparative information on their community structure and ecological status. The values for the physicochemical parameters of the lakes indicated better variables for OxBow lake. Their turbidity values were higher than the <3NTU limit. The nitrate values ranged from 6.87±0.38 to 10.32±0.17 mg/L and phosphate ranged from 1.98±0.45 to 4.46±0.64 mg/L for Igbeba-Ago and OxBow lake respectively, which were close to the 10mg/L (nitrate) and 5mg/L (phosphate) limits. Bacillariophyceae, Cyanophyceae and Chlorophyceae were identified in both Lakes; Igbeba-Ago lake had 5 taxa (24 plankters) while OxBow lake had 10 taxa (877 plankters). Copepods and Cladocerans were identified in both Lakes. Igbeba-Ago Lake hosted fewer species (8) but exhibited a higher abundance of plankters (214), with Odonata being present—an observation not made in OxBow Lake, which had 10 species and 114 plankters. The diversity indices for phytoplankton and zooplankton suggested the effects of stress linked to nutrients load, inflow and anthropogenic influences. These implied moderate pollution in both Lakes, validated by the presence of 'contaminant tolerant species' - Microcystis sp and Chlorella sp. There is need for regular monitoring of these water bodies to ensure that, the guidelines for water quality are maintained for their productivity and the ecosystem services that they provide.

Keywords: Lake, productivity, anthropogenic influences, plankton, nutrients.

INTRODUCTION

The quality of surface waters in Nigeria are generally poor due to anthropogenic inputs and hydrogeological interactions (Ighalo and Adeniyi, 2020) that contaminate water, resulting in significant deterioration of water quality. Surface waters include rivers, lakes, springs, creeks, dams and reservoirs, and lagoons sourced from major rivers and tributaries. Plankton which are floating, microscopic plants and animals are found in water bodies. They are major contributors of biomass and are crucial to the productivity and sustainability of the aquatic ecosystem (Harris and Vinobaba, 2012). The plankton communities are the basic resources that link higher trophic levels in aquatic food webs (Sindt and Wolf, 2021). Plankton comprise of phytoplankton and zooplankton, and reflect the composite influence of different parameters of water quality in the water body (Gharib *et al.*, 2011). Phytoplankton constitute the base of the aquatic food chain, producing organic and inorganic substances through carbon dioxide and photosynthesis. Zooplankton are essential components of aquatic food webs as primary consumers and they respond quickly to environmental changes, and have been used in the assessment of aquatic ecosystems (Xiong *et al.*, 2016; Malik *et al.*, 2020).

Patterns of phytoplankton and zooplankton diversity and abundance can reflect the composition of

nutrients, organic matter and sediments in water bodies. Several physical, chemical and biological factors like temperature, light, organic matter, electrical conductivity, grazing intensity, nutrients levels, and water mixing influence the production and composition of phytoplankton in aquatic ecosystems (Wang *et al.*, 2015; Hardikar *et al.*, 2017). The concentration of nutrients, especially nitrogen (N) and phosphorus (P) are the principal limiting factors for phytoplankton production in lakes and reservoirs (Wang *et al.*, 2015). Phytoplankton respond in their abundance, distribution and community structure to changes in environmental conditions (Jose *et al.*, 2015; Abdul *et al.*, 2016), while the abundance, distribution and community structure of zooplankton are in response to the phytoplankton. The species diversity, composition and abundance of the plankton communities have been used as bio-indicators of water quality, overall functioning, trophic status (Stamou *et al.*, 2021) and ecological status of aquatic ecosystems. Due to the short life span and fast regeneration of plankton, their composition, abundance and distribution fluctuate in response to temporal and spatial variations in the physicochemical and environmental conditions. The variations of plankton assemblages in freshwater ecosystems are influenced by space and time, wind speed and rainfall, light, temperature, water mixing and nutrients loading associated with seasonal changes, besides anthropogenic inputs.

Oxbow lake is an inland water body located in the urban area in Yenegoa, Bayelsa State. It is a well-known tourism attraction site with settlements and fishing activities around it with evidences of anthropogenic influences on the water body. Igbeba-Ago lake is in Agudama-Ekpetiama in the state, is a remotely located lake with farms located close by. This study, assessed the physicochemical quality, nutrient levels (nitrate and phosphate), phytoplankton and zooplankton assemblages, and the diversity indices in OxBow and Igbeba-Ago Lakes in Bayelsa State, Nigeria so as to compare their productivity and establish their ecological status.

MATERIALS AND METHODS

OxBow Lake (Plate 1) in Yenegoa, Bayelsa State, Nigeria (with coordinates 34° 38'–32° 50' N and

120° 62'– 114° 46'E), a U-shaped Lake formed from a wide meander of a river cut off, is a large, open tropical lake and tourist site with surrounding settlements and anthropogenic activities. Igbebo-Agbo Lake (Plate 2) in Agudama-Ekpetiama, Bayelsa State, Nigeria (within the coordinates, Longitude 6° 15'31.980" and Latitude 5° 0'28.662"), is a small, enclosed tropical lake with farm lands close by. Both lakes and others like these located in the state are natural water bodies. Each body of water has its variable physicochemical parameters, dynamic phytoplankton and zooplankton communities, and nutrients dynamics influenced by intrinsic (seasons, climate, etc.) and extrinsic (anthropogenic inputs) factors (Oni *et al.*, 2020).



Plate 1: A view of OxBow Lake



Plate 2: A view of Igbeba-Ago Lake

Sample Collection

Water, sediments, phytoplankton and zooplankton samples were collected from three delineated sites/locations (designated Sites A, B and C) along Igbeba-Ago Lake in Agudama-Ekpetiama and OxBow Lake, Yenegoa based on accessibility following standard protocols. Samples were collected in triplicates for analyses and sampling of these water bodies were carried out in May 2023 between 8:00 and 11:00 am.

Water samples were collected from the three sampling stations (designated Sites A, B and C) in triplicates using well labelled, sterilized, wide-mouth plastic bottles (0.75L) which were rinsed with the respective lake water before collection to prevent contamination of samples and then tightly covered with their lids. The collected samples were placed in an ice chest to maintain the integrity of the samples before analysis.

Sediment samples were collected per sampling station in triplicates using Eckman Grab which were transferred accordingly into the respective well labelled, sterilized, black polyethylene bags. The samples in the bags were tied tightly, placed in an ice chest (for sample integrity) before transporting to the laboratory for nutrient (nitrate and phosphate) analyses.

Phytoplankton samples were collected with aid of a plankton net with a mesh size of 30-70nm with a 0.5m diameter, 2m long conical plankton net. The water samples were collected in triplicates per sampling station, carefully dispensed accordingly into the respective well labelled, sterilized, wide-mouthed plastic containers with tight lids and immediately fixed with 2drops of 4% formalin for preservation, stored in an ice chest before

transporting to the laboratory for identification and enumeration.

Zooplankton samples were collected in triplicates per sampling station using the plankton net and dispensed into well labelled, sterilized, wide-mouth plastic containers with tight lids. The samples were preserved using 5drops of formalin to prevent deterioration of samples and then tightly covered with their lids before transporting to the laboratory for analyses.

Laboratory Analysis

The analysis of physicochemical parameters of the water samples from the lakes followed standard methods (APHA *et al.*, 2012). The parameters evaluated were dissolved oxygen (DO), water temperature, pH, total dissolved solids (TDS), salinity, electrical conductivity (EC) and turbidity. The surface water temperature, pH, DO, EC, TSD and Salinity were measured *in-situ* using portable EXTECH Multi-probe (DO-700) meter. The turbidity was measured using HANNA Turbidimeter (HI93414). Prior to analysis, all meters were calibrated with the appropriate standards to ensure accuracy.

Nitrate in sediments was analyzed according to Chemical Analysis for Ecological Matter -CAEM/APHA (4500-NO₃-E) Colorimetric method. The dried sediment sample was weighed (1.00g) into an extraction bottle and 25ml of distilled water was added. This sample was placed in a shaking water bath for 10minutes after which the suspension formed was filtered using an 11cm Whatman filter paper. A procedural blank of distilled water was carried out to compensate for contamination due to the filtration process. 10ml of this extract was transferred into a 100ml beaker and the content of one sachet of NitraVer 6 pillow was added to it and stirred for 1minute. This was allowed to stand for 10minutes. 8ml of this mix was transferred into a 10ml test tube and cooled in a refrigerator for 30minutes at 2–6°C, after which 2ml of the colour-producing reagent was added and mixed quickly. This was kept in the refrigerator for 30minutes and then placed on the workbench to equilibrate at room temperature for about 20minutes (CAEM, 1989; APHA, 2012). This was then analysed by filling a 1cm cell with the mix, and the cell placed inside the cell holder of Agilent 8453 UV-VIS® which measured the concentration of nitrate as read off in the instrument.

Phosphate in sediments was analysed according to the CAEM-stannous chloride reduction method. 1g of dried sediment sample was transferred into an extraction bottle into which 25ml of an extracting solution (2.5% acetic acid) was added. This was placed in a shaking water bath for 30minutes and allowed to settle before filtering the suspension

using a Whatman filter paper into a 100ml beaker. 10ml of the extract was transferred into a 50ml volumetric flask. 2ml each of molybdate and stannous chloride reagents was added to the extract and made up to 50ml using distilled water. This was mixed thoroughly and allowed to stand for 30minutes. A procedural blank of distilled water was prepared along with the samples to correct for contamination due to the process (CAEM, 1989). This was analysed by filling a 1cm cell with the sample, and the cell was placed inside the cell holder of Agilent 8453 UV-VIS® used to measure the concentration of phosphate read off in the instrument.

The analytical data quality was guaranteed through the implementation of laboratory quality assurance and quality control methods, including the use of standard operating procedures (SOP), calibration with standards, analysis of reagent blanks, recovery of known additions, and analyses in triplicates.

In the laboratory, the phytoplankton samples were allowed to stand for 24hours to settle by gravity before the supernatant was carefully pipetted off until a 50ml volume concentrated sample was achieved. From this stock sample, 1ml sub-sample was taken using a Pasteur pipette and transferred into a Bogorov counting chamber, the organisms were identified with the aid of a binocular microscope using appropriate keys according to identification guides of Botes (2003) and Robert *et al.* (2012).

For the zooplankton, the samples were allowed to settle for 24hours after which they were decanted to 50ml. From the 50ml, 1ml was taken using pipette and placed on a Bogorov counting chamber, the organisms were identified with the aid of a binocular microscope using appropriate keys according to Johnson and Allen (2005); Suthers and Rissik (2009).

Statistical Analysis

Data obtained were analyzed for mean and standard deviation of the measured parameters (physicochemical parameters, nitrate and phosphate). One-way Analysis of Variance (ANOVA) was employed to compare the differences between the means of the parameters (at $P < 0.05$) for each water body. Analysis was aided by the use of SPSS® version 2.1.0 software.

The data obtained for phytoplankton and zooplankton were analyzed using Paleontological statistics software package by Hammer *et al.* (2001). The diversity indices (Simpson, Shannon diversity, Dominance, Evenness, Brillion, Margelef, Menhinick, Equitability and Fisher_alpha) were also determined accordingly.

RESULTS**Physicochemical Parameters**

The values of the mean (\pm standard deviation) of the physicochemical parameters determined for Igbeba-Ago and OxBow Lakes were significantly ($P < 0.05$) different with respect to sampling sites and between the lakes as shown in Table 1. The values showed that, the pH ranged from 6.38 ± 0.02 to 6.58 ± 0.02 and 6.53 ± 0.02 to 6.65 ± 0.03 ; temperature ranged from

27.88 ± 0.08 to $28.23 \pm 0.05^\circ\text{C}$ and 27.39 ± 0.02 to $27.90 \pm 0.03^\circ\text{C}$; and dissolved oxygen (DO) ranged from 4.20 ± 0.02 to 4.73 ± 0.04 mg/L and 5.06 ± 0.06 to 5.67 ± 0.07 mg/L for Igbeba-Ago Lake and OxBow Lake respectively. The values of the physicochemical parameters of both lakes were within the standard ranges provided as limits by FEPA (2003), WHO (2008) and USEPA (2011).

Table 1: Mean Values of the Determined Physicochemical Parameters of Igbeba-Ago Lake and Oxbow Lake in Bayelsa State, Nigeria

| PARAMETER/SAMPLING SITES | Mean \pm Std. Deviation of Parameters for Igbeba Ago Lake | Mean \pm Std. Deviation of Parameters for OxBow Lake | FEPA (2003) | WHO (2008) | USEPA (2011) |
|----------------------------------|---|--|-------------|------------|--------------|
| pH | A | 6.38 ± 0.02^a | | | |
| | B | 6.47 ± 0.06^b | 6.5-8.5 | 6.5-8.5 | 6.5-8.5 |
| | C | 6.58 ± 0.02^c | | | |
| Temperature ($^\circ\text{C}$) | A | 27.88 ± 0.08^a | | | |
| | B | 28.14 ± 0.09^b | 26 | <40 | - |
| | C | 28.23 ± 0.05^b | | | |
| DO (mg/L) | A | 4.20 ± 0.03^a | | | |
| | B | $4.26^b \pm 0.04^b$ | 5.0-7.0 | > 4 | - |
| | C | 4.73 ± 0.04^c | | | |
| Salinity (mg/L) | A | 2.31 ± 0.00^a | - | <600 | - |
| | B | 2.47 ± 0.01^b | | | |
| | C | 2.72 ± 0.02^c | | | |
| EC ($\mu\text{S/cm}$) | A | 144.87 ± 1.11^a | | | |
| | B | 144.60 ± 0.52^a | 750 | 70 | - |
| | C | 149.25 ± 0.52^b | | | |
| TDS (mg/L) | A | 113.44 ± 0.43^b | | | |
| | B | 109.33 ± 0.34^a | 500 | 500 | 500 |
| | C | 113.31 ± 0.55^b | | | |
| A | 87.78 ± 0.36^a | 62.83 ± 0.86^c | <3 | <3 | <3 |

| | | | |
|---------------------------|----------|---------------------------|-------------------------|
| Turbidity (NTU) | B | 89.16 ± 0.71 ^b | 57.85±1.29 ^b |
| | C | 87.78 ± 0.32 ^a | 44.24±0.26 ^a |

Key: Means with the same superscripts are not statistically different $P>0.05$, within the column for each parameter. DO=Dissolved Oxygen; pH= Potential Hydrogen; EC= Electrical Conductivity; TDS= Total Dissolved Solids; WHO= World Health Organization; FEPA= Federal Environmental Protection Agency; USEPA= United States Environmental Protection Agency.

Nutrients

From the results (Table 2), nitrates values ranged from 6.87 ± 0.38 to 9.95 ± 0.89 mg/L while phosphates ranged from 2.11 ± 0.26 to 4.11 ± 0.62 mg/L and 1.98 ± 0.45 to 4.46 ± 0.64 mg/L for Igbeba-Ago Lake and OxBow Lake respectively.

The mean values of nitrates (except in OxBow Lake) and phosphates in the lakes were lower than the FMEVN (2001) and WHO (2021) guidelines, the values were close to the FMEVN limits (with OxBow Lake being higher).

Table 2: Mean Levels of Nitrate and Phosphate in Igbeba-Ago Lake and OxBow Lake in Bayelsa State, and the Guidelines of FMEVN (2001) and WHO (2021)

| NUTRIENT/ SAMPLING SITE | | Mean ± Standard Deviation of Nutrients Levels in Igbeba-Ago Lake | Mean ± Standard Deviation of Nutrients Levels in OxBow Lake | FMEVN Guidelines (2001) | WHO Guidelines (2021) |
|----------------------------|----------|---|--|-------------------------------|-----------------------------|
| Nitrate | A | 6.87 ± 0.38^a | 7.61 ± 0.14^a | 10mg/L | 50mg/L |
| | B | 8.93 ± 0.08^b | 8.81 ± 0.39^b | | |
| | C | 9.95 ± 0.89^b | 10.32 ± 0.17^c | | |
| Phosphate | A | 2.11 ± 0.26^a | 1.98 ± 0.45^a | 5mg/L | 10mg/L |
| | B | 4.11 ± 0.62^b | 2.99 ± 0.55^a | | |
| | C | 3.80 ± 0.12^b | 4.46 ± 0.64^b | | |

N/B: Means with the same superscripts are not statistically different $P>0.05$, within the column for each parameter. Federal Ministry of Environment Guidelines for Nitrates and Phosphates: FMEVN (2001) and World Health Organization Guidelines for Nitrates and Phosphates: WHO (2021)

Phytoplankton

The identified and enumerated phytoplankton in Table 3 showed that, three families (Bacillariophyceae, Cyanophyceae and Chlorophyceae in the order: Chlorophyceae > Cyanophyceae > Bacillariophyceae) were identified in Igbeba-Ago and OxBow Lakes. Igbeba-Ago Lake had five species while OxBow Lake had ten species. Chlorophyceae was the dominant group in Igbeba-Ago and OxBow Lakes with 63% (15) and 54% (476) composition respectively (Figs. 1a and b), indicating higher phytoplankton abundance in OxBow Lake (Fig. 2). The results in Table 3 showed that, the family: Cyanophyceae had only one species (*Microcystis aeruginosa*) identified in

Igbeba-Ago Lake while four species (*Cylindrospermopsis raciborskii*, *Microcystis aeruginosa*, *Spirulina* sp. and *Coelosphaerium* sp.) were identified in OxBow Lake. The family: Chlorophyceae had two species (*Spirogyra* sp. and *Chlorella* sp.) identified in Igbeba-Ago Lake while four species (*Spirogyra* sp., *Ulothrix* sp., *Chlorella* sp. and *Pediastrum* sp.) were identified in OxBow Lake. In total, Igbeba-Ago Lake had 24 plankters with *Spirogyra* sp (11) as the dominant species while OxBow Lake had 877 plankters with *Cylindrospermopsis raciborskii* (380) as the dominant species; indicating higher planktic number in the latter.

Table 3: Phytoplankton in Igbeba-Ago Lake and Oxbow Lake in Bayelsa State during the Sampling Period

| Taxonomic Group | Igbeba-Ago Lake | | | | Oxbow Lake | | | |
|---------------------------------------|-----------------|----------|-----------|-----------|------------|------------|-----------|------------|
| | Site A | Site B | Site C | Total | Site A | Site B | Site C | Total |
| BACILLARIOPHYCEAE | | | | | | | | |
| <i>Synedra</i> sp | 3 | 3 | 0 | 6 | 0 | 0 | 2 | 2 |
| <i>Asterionella</i> sp | 1 | 0 | 0 | 1 | 0 | 0 | 3 | 3 |
| Sub-total | 4 | 3 | 0 | 7 | 0 | 0 | 5 | 5 |
| CYANOPHYCEAE | | | | | | | | |
| <i>Cylindrospermopsis raciborskii</i> | 0 | 0 | 0 | 0 | 225 | 76 | 79 | 380 |
| <i>Microcystis aeruginosa</i> | 2 | 0 | 0 | 2 | 3 | 0 | 3 | 6 |
| <i>Spirulina</i> sp | 0 | 0 | 0 | 0 | 0 | 3 | 1 | 4 |
| <i>Coelosphaerium</i> sp | 0 | 0 | 0 | 0 | 2 | 0 | 4 | 6 |
| Sub-total | 2 | 0 | 0 | 2 | 230 | 79 | 87 | 396 |
| CHLOROPHYCEAE | | | | | | | | |
| <i>Spirogyra</i> sp | 2 | 2 | 7 | 11 | 115 | 81 | 49 | 245 |
| <i>Ulothrix</i> sp | 0 | 0 | 0 | 0 | 105 | 72 | 48 | 225 |
| <i>Chlorella</i> sp | 0 | 0 | 4 | 4 | 3 | 0 | 0 | 3 |
| <i>Pediastrum</i> sp | 0 | 0 | 0 | 0 | 1 | 2 | 0 | 3 |
| Sub-total | 2 | 2 | 11 | 15 | 224 | 155 | 97 | 476 |

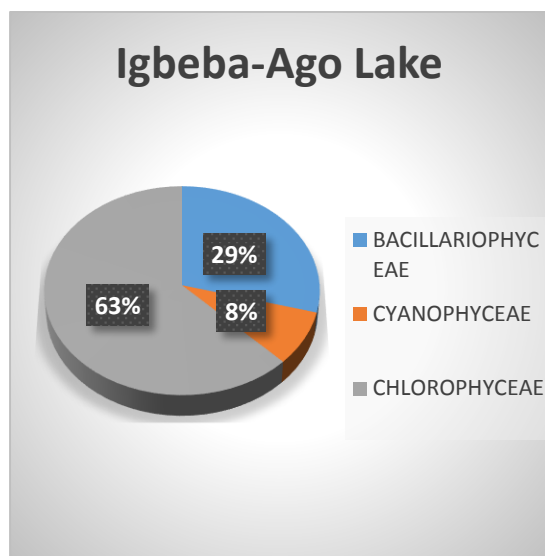


Fig. 1a: Occurrence of the Identified Phytoplankton Groups in Igbeba-Ago Lake

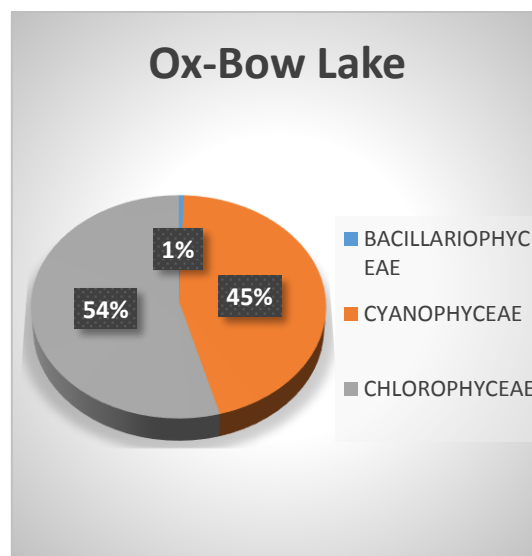


Fig. 1b: Occurrence of the Identified Phytoplankton Groups in Ox-Bow Lake

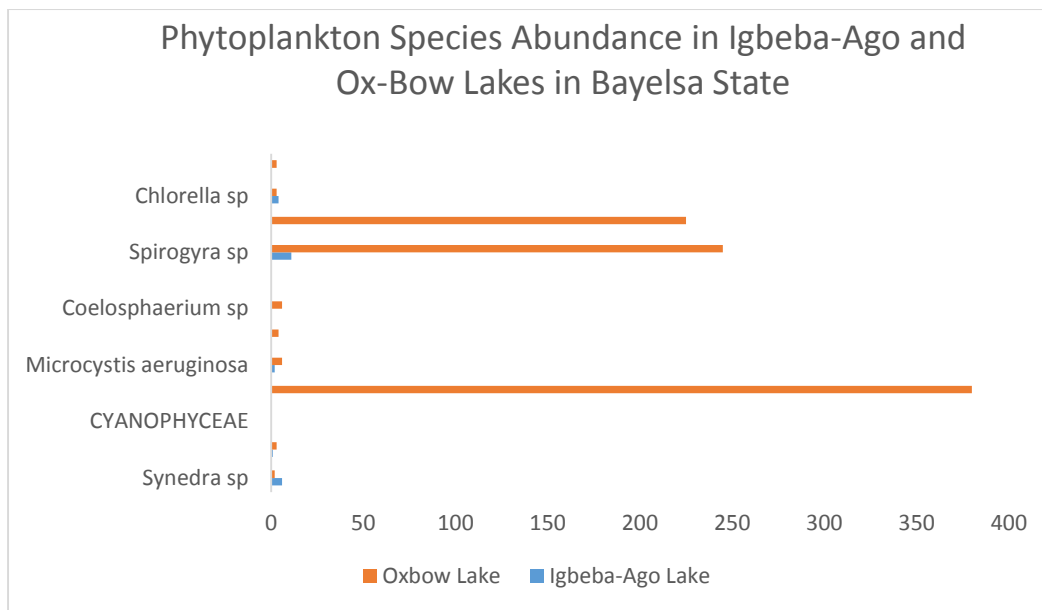


Fig. 2: Phytoplankton Species Abundance in Igbeba-Ago and Ox-Bow Lakes in Bayelsa State

Diversity Indices

Based on the diversity indices as shown in Table 4, there were 5 and 10 species; 24 and 877 plankters identified in Igbeba-Ago and OxBow Lakes respectively. The dominance indices showed that, Site C (0.54) and Site A (0.36) had dominance in Igbeba-Ago and OxBow Lakes respectively with the latter having a general higher dominance (0.33). For the Simpson index, Igbeba-Ago Lake had a value of 0.69 with Site A at 0.72 while OxBow Lake

had a value of 0.67 with Site C as 0.69. The Brillouin index, Menhinick index and Margalef index had values of 1.12 and 1.21; 1.02 and 0.34; and 1.26 and 1.33 for Igbeba-Ago and OxBow Lakes respectively. The Shannon indices gave values of 1.342 in Igbeba-Ago Lake with Site A at 1.32 while OxBow Lake was 1.23 with Site C at 1.35 in OxBow Lake (as the 1.23 as the total). For the Evenness, Igbeba-Ago had 0.77 while OxBow had 0.34 which was lower.

Table 4: Diversity Indices of Phytoplankton in Igbeba-Ago Lake and Oxbow Lake in Bayelsa State

| Indices | Sampling Locations | | | | | | | |
|----------------|--------------------|--------|--------|-------|------------|--------|--------|-------|
| | Igbeba-Ago Lake | | | | Oxbow Lake | | | |
| | Site A | Site B | Site C | Total | Site A | Site B | Site C | Total |
| Taxa_S | 4 | 2 | 1 | 5 | 7 | 5 | 8 | 10 |
| Individuals | 8 | 5 | 11 | 24 | 454 | 234 | 189 | 877 |
| Dominance | 0.28 | 0.52 | 0.54 | 0.31 | 0.36 | 0.32 | 0.3075 | 0.33 |
| Simpson | 0.72 | 0.48 | 0.46 | 0.69 | 0.64 | 0.68 | 0.6925 | 0.67 |
| Shannon | 1.32 | 0.67 | 0.66 | 1.34 | 1.14 | 1.19 | 1.352 | 1.23 |
| Evenness | 0.94 | 0.98 | 0.96 | 0.77 | 0.45 | 0.66 | 0.483 | 0.34 |
| Brillouin | 0.93 | 0.46 | 0.53 | 1.12 | 1.11 | 1.16 | 1.287 | 1.21 |
| Menhinick | 1.41 | 0.89 | 0.60 | 1.02 | 0.33 | 0.33 | 0.5819 | 0.34 |
| Margalef | 1.44 | 0.62 | 0.42 | 1.26 | 0.98 | 0.73 | 1.335 | 1.33 |
| Equitability_J | 0.95 | 0.97 | 0.95 | 0.83 | 0.59 | 0.74 | 0.65 | 0.54 |
| Fisher_alpha | 3.18 | 1.24 | 0.72 | 1.92 | 1.18 | 0.90 | 1.694 | 1.58 |

The findings in this study were similar to the works of Esenowo *et al.* (2017), on Nwaniba River, Akwa Ibom State, Nigeria; Ogamba *et al.* (2019b), on

Taylor Creek, Bayelsa State, Nigeria; and Nwonumara *et al.* (2022), on Ufiobodo and Ebonyi Reservoirs, Ebonyi State, Nigeria. The dynamics of

the physicochemical parameters, nutrients, run-offs, inflow (from the source river) and anthropogenic inputs all had their effects on the values of the diversity indices observed in this study. The occurrence of certain species in lakes are associated with the introduction of organic pollution (Yusuf, 2020). This results in the need for the monitoring of water quality and plankton assessments (Ighalo and Adeniyi, 2020). Cyanobacterial blooms are potentially toxic (Akagha *et al.*, 2020), such blooms (mainly *Microcystis* sp.) have toxic impacts on fishes (Yu *et al.*, 2021). The presence of *Microcystis* sp, an indication of eutrophic water and *Chlorella* sp, an indication of organic contamination; especially high phosphate levels (Reynolds and

Lund 2006) as were observed in Igbeba-Ago and OxBow Lakes were indications of the contamination of these water bodies, which also reflected in their nitrate and phosphate levels.

Zooplankton

From the results in Table 5, three zooplankton groups: Copepods, Cladocera and Insecta (in the order: Cladocera > Copepods > Insecta) were identified in Igbeba-Ago Lake with 8 species and *Diaphanosoma* sp (36%) as the dominant species (Fig. 3a) with a total of 214 plankters while OxBow Lake had only Copepods and Cladocera (in the order: Cladocera > Copepods) with 10 species and *Daphnia rosea* (26%) as the dominant species (Fig. 3b) with a total of 116 plankters.

Table 5: Distribution of Zooplankton in Igbeba-Ago Lake and OxBow Lake in Bayelsa State during the Sampling Period

| Taxa/Individuals | Igbeba-Ago Lake | | | | OxBow Lake | | | |
|------------------------------|-----------------|-----------|-----------|------------|------------|-----------|-----------|-----------|
| | Site A | Site B | Site C | Total | Site A | Site B | Site C | Total |
| COPEPODA | | | | | | | | |
| <i>Epischura lacustris</i> | 23 | 9 | 4 | 36 | 4 | 6 | 9 | 19 |
| <i>Nauplius pulex</i> | - | - | - | - | 0 | 3 | 4 | 7 |
| <i>Limnocalanus macrurus</i> | 29 | 13 | 4 | 46 | 3 | 0 | 13 | 16 |
| <i>Senecella calanoides</i> | - | - | - | - | 1 | 0 | 2 | 3 |
| <i>Eucyclops serrulatus</i> | 8 | 3 | 4 | 15 | 2 | 2 | 7 | 11 |
| <i>Epischura lacustris</i> | - | - | - | - | 4 | 6 | 9 | 19 |
| <i>Diaptomus siciloides</i> | 2 | 0 | 0 | 2 | 2 | 0 | 0 | 2 |
| Sub-total | 62 | 25 | 12 | 99 | 16 | 17 | 44 | 77 |
| CLADOCERA | | | | | | | | |
| <i>Daphnia rosea</i> | 10 | 3 | 12 | 25 | 9 | 4 | 12 | 25 |
| <i>Bosmina longirostris</i> | 2 | 1 | 4 | 7 | 2 | 2 | 4 | 8 |
| <i>Diaphanosoma</i> sp | 50 | 14 | 14 | 78 | 4 | 2 | 0 | 6 |
| Sub-total | 62 | 18 | 30 | 110 | 15 | 8 | 16 | 39 |
| INSECTA | | | | | | | | |
| Odonata | 0 | 3 | 2 | 5 | 0 | 0 | 0 | 0 |
| Sub-total | 0 | 3 | 2 | 5 | 0 | 0 | 0 | 0 |

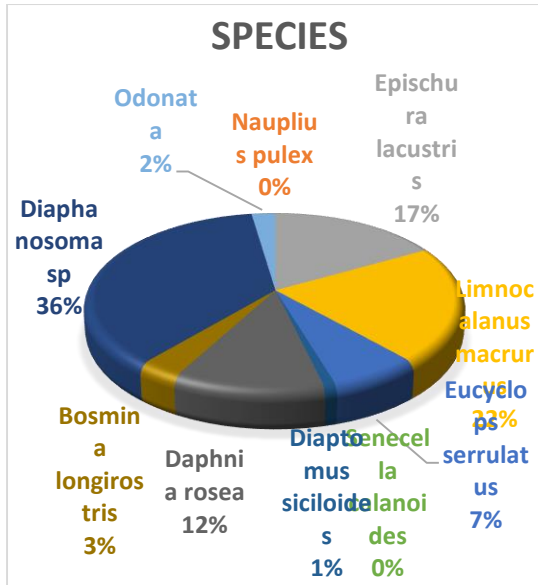


Fig. 3a: Zooplankton Abundance in Igbeba-Ago Lake

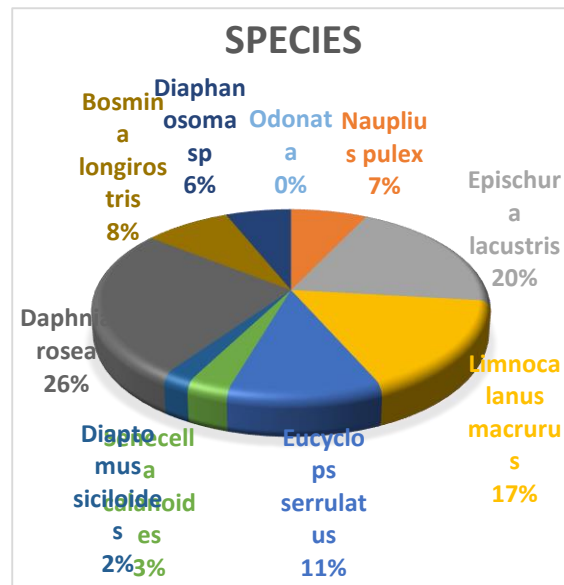


Fig. 3a: Zooplankton Abundance in OxBow Lake

Diversity Indices

From the diversity indices for zooplankton as shown in Table 6, there were 8 and 10 groups, and 214 and 116 plankters in Igbeba-Ago and OxBow Lakes respectively with a dominance of 0.23 and 0.16

respectively, indicating dominance of competitive species leading to low diversity in Igbeba-Ago Lake compared with OxBow Lake which was better than the former.

Table 6: Diversity Indices of Zooplanktons in Igbeba-Ago Lake and OxBow Lake in Bayelsa State during the Sampling Period

| Indices | Igbeba-Ago Lake | | | | OxBow Lake | | | |
|----------------|-----------------|--------|--------|-------|------------|--------|--------|-------|
| | Site A | Site B | Site C | Total | Site A | Site B | Site C | Total |
| Taxa_S | 7 | 7 | 7 | 8 | 9 | 7 | 8 | 10 |
| Individuals | 124 | 46 | 44 | 214 | 31 | 25 | 60 | 116 |
| Dominance | 0.26 | 0.22 | 0.21 | 0.23 | 0.19 | 0.20 | 0.18 | 0.16 |
| Simpson | 0.74 | 0.78 | 0.79 | 0.77 | 0.82 | 0.80 | 0.82 | 0.8 |
| Shannon | 1.532 | 1.66 | 1.73 | 1.68 | 1.88 | 1.69 | 1.79 | 1.97 |
| Evenness | 0.66 | 0.75 | 0.82 | 0.67 | 0.82 | 0.91 | 0.86 | 0.80 |
| Brillouin | 1.44 | 1.46 | 1.52 | 1.61 | 1.52 | 1.35 | 1.60 | 1.82 |
| Menhinick | 0.63 | 1.03 | 1.06 | 0.55 | 1.54 | 1.38 | 0.98 | 0.91 |
| Margalef | 1.25 | 1.57 | 1.59 | 1.31 | 2.12 | 1.70 | 1.53 | 1.75 |
| Equitability_J | 0.79 | 0.85 | 0.89 | 0.81 | 0.90 | 0.95 | 0.92 | 0.90 |
| Fisher_alpha | 1.61 | 2.30 | 2.35 | 1.64 | 3.84 | 3.02 | 2.20 | 2.42 |

The Shannon index values were 1.73 for Site C in Igbeba-Ago Lake (with a total of 1.68) and 1.79 for Site C in OxBow Lake (with a total of 1.97). The Simpson index values were 0.77 and 0.84 for Igbeba-Ago and OxBow Lakes respectively. The Menhinick index and Margalef index for species richness had values of 0.55; 0.91 and 1.31; 1.75 for Igbeba-Ago and OxBow Lakes respectively. These were in tandem with the Brillouin index values of 1.82 for OxBow Lake compared to 1.61 for Igbeba-Ago Lake. The Evenness index was 0.80 in OxBow Lake and 0.67 in Igbeba-Ago Lake. The Fisher's alpha index was 1.64 for Igbeba-Ago and 2.42 for OxBow Lake. The equitability index values was 0.81 for Igbeba-Ago Lake while OxBow Lake was 0.90.

DISCUSSION

The physicochemical parameters showed that OxBow Lake had higher pH and DO values than Igbeba-Ago Lake with the mean values for water temperature, TDS, salinity, conductivity and turbidity higher in the latter. Generally, OxBow had better values than Igbeba-Ago Lake. Except for turbidity which was higher in both lakes than the guidelines, indicative of the presence of suspended matter which were attributable to the alluvial/colloidal nature of the water of the Niger River, vegetation around the water bodies that fall in and decay, and run-offs. The values of the physicochemical parameters (which are important for aquatic life) of both lakes were within the ranges provided as limits by FEPA (2003), WHO (2008) and USEPA (2011). The values of the physicochemical parameters were also in line with ranges from studies of other coastal water bodies in Nigeria (Ajibare *et al.*, 2019; Nwonumara *et al.*, 2022). Hence, the water quality of both lakes can be said to be suitable for aquatic life.

The nitrate values were higher in OxBow Lake than Igbeba-Ago Lake but the phosphate values were converse; attributable to inflow, anthropogenic influences and run-offs. The values in this study were lower than the values of Omoruyi and Oghuvwu (2018), who reported high levels of nitrate and phosphate in Ikpoba River of Edo State, Nigeria and Isiuku and Enyoh, (2020), on some rivers and lakes in Imo State, Nigeria. The values though, were similar to the values from Uzochukwu *et al.* (2019), of Ekulu River, Enugu State, Nigeria but contrary to findings of Oyatola *et al.* (2021), on coastal waters in Ilaje, Ondo State, Nigeria with lower nitrate values and higher phosphate values. Nitrates and phosphates are nutrients essential for primary production (plant growth and the build-up of the aquatic food web based on phytoplankton growth and zooplankton community) and aquatic productivity. These nutrients are required at certain levels for optimum productivity but when nitrate and

phosphate concentrations are in excess in water bodies, they result in the overgrowth of hydrophytes (especially algae) leading to eutrophication and algal bloom which can be harmful. Since their death and decomposition result in high consumption of dissolved oxygen in the water causing anoxic conditions and increased sedimentation, resulting in the deterioration of the water quality (Brubaker, 2014; Moshoeshoe and Obuseng, 2018; Tao *et al.*, 2021). Thereby, causing change in aquatic structure, function and the communities with eventual hypoxia leading to dead zone. This is besides harmful algal blooms (HABs) that can directly threaten fish and human health. Nitrates and phosphates are serious problems in many waterways (Brubaker, 2014). Though, the mean values of nitrates (except in OxBow Lake) and phosphates in the study areas were lower than the FMEVN (2001) and WHO (2021) guidelines, the values were close to the FMEVN limits (with OxBow Lake being higher). These values portend threats of nutrients enrichment/ build-up and eutrophication hence, the need for the monitoring of these water bodies.

Generally, OxBow lake was richer in phytoplankton while Igbeba-Ago Lake was richer in zooplankton. For the phytoplankton, similar to the findings of this study, Ogamba *et al.* (2019), reported higher abundance of Chlorophyceae and Bacillariophyceae in Taylor creek in Bayelsa State, Nigeria. Davies *et al.* (2019), had similar findings for Orashi River in Rivers State, Nigeria. Studies by Nwonumara *et al.* (2022), for Ufiobodo and Ebonyi Reservoirs in Ebonyi State, Nigeria; Kondowe *et al.* (2022), for Lake Kanyaboli, in Kenya; Yirga and Wagaw (2023), for Lake Arkiet, a tropical lake in Ethiopia; and Ezenweani *et al.* (2023), for Aiakhuakhuari River in Oredo Local Government Area, Edo State, Nigeria also reported similar findings of higher abundance of Chlorophyceae and Bacillariophyceae, though, the species reported varied.

The values for the zooplankton in this study were similar to the findings of Ogamba *et al.* (2019), for Taylor Creek, Bayelsa State, Nigeria; Iyiakwu River in Southeast Nigeria (Anyanwu *et al.*, 2022); and Lake Kanyaboli in Kenya (Kondowe *et al.*, 2022).

With respect to the diversity indices, the dominance value shows the fraction of common/occurring species. According to the competitive exclusion principle, 'stable environmental conditions are associated with the dominance of few competitive species, leading to low diversity which suggests that, the superior competitor species would dominate a constant environment and lead to a low community richness and diversity' (Figueredo and Giani, 2009) which was the case for the phytoplankton in the studied lakes especially Igbeba-Ago Lake. The Shannon diversity index is a measure of diversity.

Basically, this index range from 0 – 5, where; <1 indicates heavy pollution, 1 to 2 indicates moderate pollution, and >3 indicates stable conditions (Magurran, 2004; Shah and Pandit, 2013). From the Shannon indices, Igbeba-Ago Lake (1.34) and OxBow Lake (1.23) indicated moderate pollution of both Lakes. Simpson index is an indication of the community. High Simpson index is an indication of mature and stable community while low values may suggest the effects of stress. Igbeba-Ago Lake (0.69) and OxBow Lake (0.67) indicated stable phytoplankton communities with Igbeba-Ago Lake (0.69) having higher index value. The Evenness provides information about the relative number of individuals in the sample, Igbeba-Ago had 0.77 while OxBow had 0.34 which was lower. The Margalef index and Menhinick index usually consider the species richness across the study area while the Brillouin index measures the diversity/abundance of species. The Brillouin index, Menhinick index and Margalef index had values of 1.12 and 1.21; 1.02 and 0.34; and 1.26 and 1.33 for Igbeba-Ago and OxBow Lakes respectively indicating that, the latter had higher species richness and abundance. This was confirmed by the Fisher's alpha index which provides useful information about species richness and equitability index values which basically range from 0 and 1. Higher and lower equitability index values is an indication of low and high diversity respectively; and provides information about the spread of the species and variability of the species in the various locations (Hossain *et al.*, 2017). The equitability index values indicated that, OxBow Lake (0.54) had higher species diversity.

The diversity indices for the zooplankton had Shannon index values for Igbeba-Ago Lake (1.68) and OxBow Lake (1.97), indicating moderate pollution. This was similar to the findings of Ogamba *et al.* (2019), on Taylor Creek in Bayelsa State, Nigeria. The Simpson index values were 0.77 and 0.84 for Igbeba-Ago and OxBow Lakes respectively which implied that, there was a stable zooplankton community in OxBow Lake while Igbeba-Ago was under the effect of stress. The Menhinick index and Margalef index for species richness had values of 0.55; 0.91 and 1.31; 1.75 for Igbeba-Ago and OxBow Lakes respectively, indicating higher species richness in OxBow Lake validated by the Brillouin index values of 1.82 compared to 1.61 for Igbeba-Ago Lake. The Evenness index provides information about relative number of individuals in the sample which was 0.80 in OxBow Lake and 0.67 in Igbeba-Ago Lake, a reflection of anthropogenic influences. The Fisher's alpha index provides useful information about species richness, and the equitability index values which basically range from 0 and 1 with higher and lower values as indication of low and high diversity respectively; and provides information about the

spread of the species and variability of the species (Hossain *et al.*, 2017), indicated that, Igbeba-Ago Lake (0.81) had higher species diversity than OxBow Lake (0.90). These findings were similar to that of Anyanwu *et al.* (2022), on the diversity indices for zooplankton taxa in Iyiakwu River, Southeast Nigeria.

CONCLUSION

The values of the physicochemical variables of Igbeba-Ago and OxBow Lakes indicated better variables for OxBow Lake but the turbidity values of both Lakes were higher than the guidelines, indicative of suspended matter attributable to extrinsic influences. The nutrient quality reflected in the values of nitrates and phosphates were close to the limits with OxBow Lake being higher especially for nitrates. This portends threat of nutrient build up which may lead to eutrophication. The phytoplankton assessment showed that, both lakes had the same families but OxBow Lake was richer in species and plankters than Igbeba-Ago Lake. This was converse for the zooplankton in Igbeba-Ago lake which had fewer species but higher number of plankters; and Odonata was identified which was not the case with OxBow Lake. The values of the diversity indices suggested the effects of stress linked to nutrients load, inflow and anthropogenic influences, and generally indicated moderate pollution of both Lakes, confirmed by the presence of *Microcystis* sp, and *Chlorella* sp which are contaminants tolerant species. There is therefore need for regular monitoring of the activities close to these water bodies to ensure that, guidelines for water quality are maintained to facilitate the productivity of these water bodies, as well as, the ecosystem services they provide.

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