

Spatial and temporal dynamics of the primary productivity of the Lower River Niger at Agenebode, Edo State, Nigeria

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Received 2nd May 2025; Accepted 26th July 2025

ABSTRACT: Biotic systems rely on continuous energy inputs, mostly from sunlight through primary production, to maintain their structure and order. There is a paucity of information on the primary productivity of the Lower River Niger (LRN), hence, this study investigates the variation in the primary production of LRN across time and space. LRN was stratified into three zones (A1, A2, and A3) with two sampling sites each, according to their hydrological features. Sampling was carried out between April and December, covering wet and dry seasons. Water samples were collected using a Van Dorn bottle, poured into light and dark glass bottles, and analysed using the oxygen production rate in the bottles. Data were analysed using standard statistics at $\alpha = 0.05$. The primary productivity of LNR after the consumption of energy for respiration, Net Primary Productivity (NPP, $g/O_2/m^3/d$), ranged from 0.25 ± 0.05 in A1 to 0.75 ± 0.28 in A3, with a spatial mean value of 0.45 ± 0.23 , and there was no significant difference spatially. The NPP mean value (0.58 ± 0.06) was higher in the dry season than in the wet season (0.28 ± 0.06); however, there was no significant difference seasonally. The primary productivity of the Lower River Niger of $0.75 g/O_2/m^3/d$ was low compared to those of most inland water bodies in and outside Nigeria. This may portend negative implications for the fisheries of the river. There is, therefore, a need to pay attention to the environmental considerations of this important river.

Keywords: Community respiration, gross production, net production, oxygen, photosynthesis.

INTRODUCTION

Biological systems exist as a result of constant inputs of energy to sustain the structure and order. At the level of the ecosystem, most of this power comes from sunlight that is converted into the energy of organic matter in living biomass through the process of primary production and from the imports of organic matter from adjoining ecosystems. This import of energy in organic matter is, of course, mainly dependent upon primary production in the "upstream" ecosystem. Thus, a serious aspect of understanding the functioning of an ecosystem is a precise estimate of its rate of primary production (Adeniyi and Akinwale, 2017).

Primary productivity is defined as the rate at which plants and other photosynthetic organisms manufacture organic compounds in an ecosystem (Bender *et al.*, 1987; Gregg and Rousseaux, 2019). There are two parts of primary productivity: Gross productivity (the entire photosynthetic manufacturing of organic compounds in an ecosystem), and Net productivity (the organic materials that remain after photosynthetic organisms in the ecosystem have spent some of these compounds for their cellular energy requirements (cellular respiration). Since oxygen is one of the most easily measured products of both photosynthesis and respiration, a good way to measure primary productivity

in an aquatic ecosystem is to measure dissolved oxygen. Since gross productivity cannot be determined directly, the respiration which uses up oxygen and organic compounds, is at all times occurring simultaneously with photosynthesis, can be measured indirectly (Onwuteaka and Choko, 2018; IOCCG, 2022). According to Kadiri *et al.* (2019), net productivity can be measured directly by measuring oxygen production in the light, when photosynthesis is occurring. And respiration is measured by measuring the oxygen consumption in the dark when photosynthesis does not occur.

Net productivity is derived from the difference between gross productivity and respiration, expressed as Net productivity = Gross productivity – Respiration. Gross productivity itself can be calculated, and primary productivity is generally measured in three main ways: by assessing the quantity of carbon dioxide used during photosynthesis, by determining the rate of sugar formation, or by measuring the rate of oxygen production.

The primary productivity of a water body is the demonstration of its biological production. It is the final outcome of photosynthesis that forms the basis of ecosystem functioning since it makes the chemical energy and organic matter available to the entire biological community (Omoboye and Adeniyi, 2017). The organisms that contain chlorophyll make use of solar energy and convert it into chemical energy in the form of carbohydrate molecules by taking carbon dioxide and water from the environment (Patra, 1985). All freshwater ecosystems (lakes, rivers, ponds, streams, wetlands) are home to various life forms, often collectively referred to as the food chain or food web. Therefore, the numbers and variety of living organisms in a freshwater food web are dependent on the productivity of the ecosystem. Of course, the available energy is constantly changing with daily and seasonal cycles, and the raw materials are continuously cycling (water cycle, carbon cycle, nitrogen cycle, phosphorus cycle) through and within the ecosystem. These fluctuations also help to determine the short-term productivity of the system. The greater the primary production within an ecosystem, the more living biomass that can be supported within the food web (Omoboye and Adeniyi, 2017).

MATERIALS AND METHODS

Study area

Agenebode is a serene, waterside town bounded by Ivioghe, Egor, Emokweme villages, and the River Niger in Edo State, South-South geopolitical zone of Nigeria, and the headquarters of Etsako-East Local Government of Edo State. It is located on a latitude of 7°03'15" N to 7°09'15" N and a longitude of 6°39'42"E to 6°45'00"E (Figure 1).

Spatial stratification was adopted according to Southwood and Henderson (2000), in which the river was

divided into three zones (A1, A2, and A3) with two sampling sites each, according to their hydrological features. Sampling points were marked with the use of Global Positioning System GPS (Magellan, SporTrak PRO MARINE [IEC – 529 IPX7 Model]) kit to ensure proper location of the stations during each sampling exercise.

Collection of samples and field procedures

Water sampling was carried out between April and December, covering two seasons (wet and dry), and samples were collected bimonthly at early hours of the morning at a depth of 20 cm below the water surface. Water samples were collected using a Van Dorn bottle, poured into light and dark glass bottles (a black glass or covered with aluminum foil to make it opaque, while the other bottle was transparent), and suspended in a vertical position in the sampling depth for 24 hours for total primary productivity determination according to National Oceanic and Atmospheric Administration (NOAA, 2000).

Determination of productivity

Gross primary production, Net primary production, and Community respiration in the water sample for each set of samples were analysed according to Trivedy and Goel (1986) using light and dark bottles, and also the technique as described in National Oceanic and Atmospheric Administration (NOAA, 2000). At the beginning of the experiment, dissolved oxygen in the sampled water was established by the iodometric winkler's method. Likewise, at the end of incubation time (24 hours), dissolved oxygen content in fixed samples of the incubated water samples in the light and dark bottles was determined by iodometric winkler's method (Stirling, 1999).

Based on the assumption that one atom is assimilated for each molecule of oxygen (32 g) released for each molecule of carbon (12 g) fixed, productivity was calculated (APHA, 1998). The change in oxygen level in the dark bottle (a negative number) is equal to the oxygen consumed by respiration. The change in oxygen level in the light bottle (most likely a positive number) is equal to the net production (Net primary production). From these two values, the gross primary production was determined by adding the absolute value of the change in oxygen in the dark bottle to the change in oxygen in the light bottle (NOAA, 2000).

Primary production was calculated using the rate of oxygen production according to the National Oceanic and Atmospheric Administration (NOAA, 2000).

Calculation

Net Primary Production (NPP) = final DO in light bottle in mgL^{-1} (FLDO) – initial DO in light bottle in mgL^{-1} (ILDO)

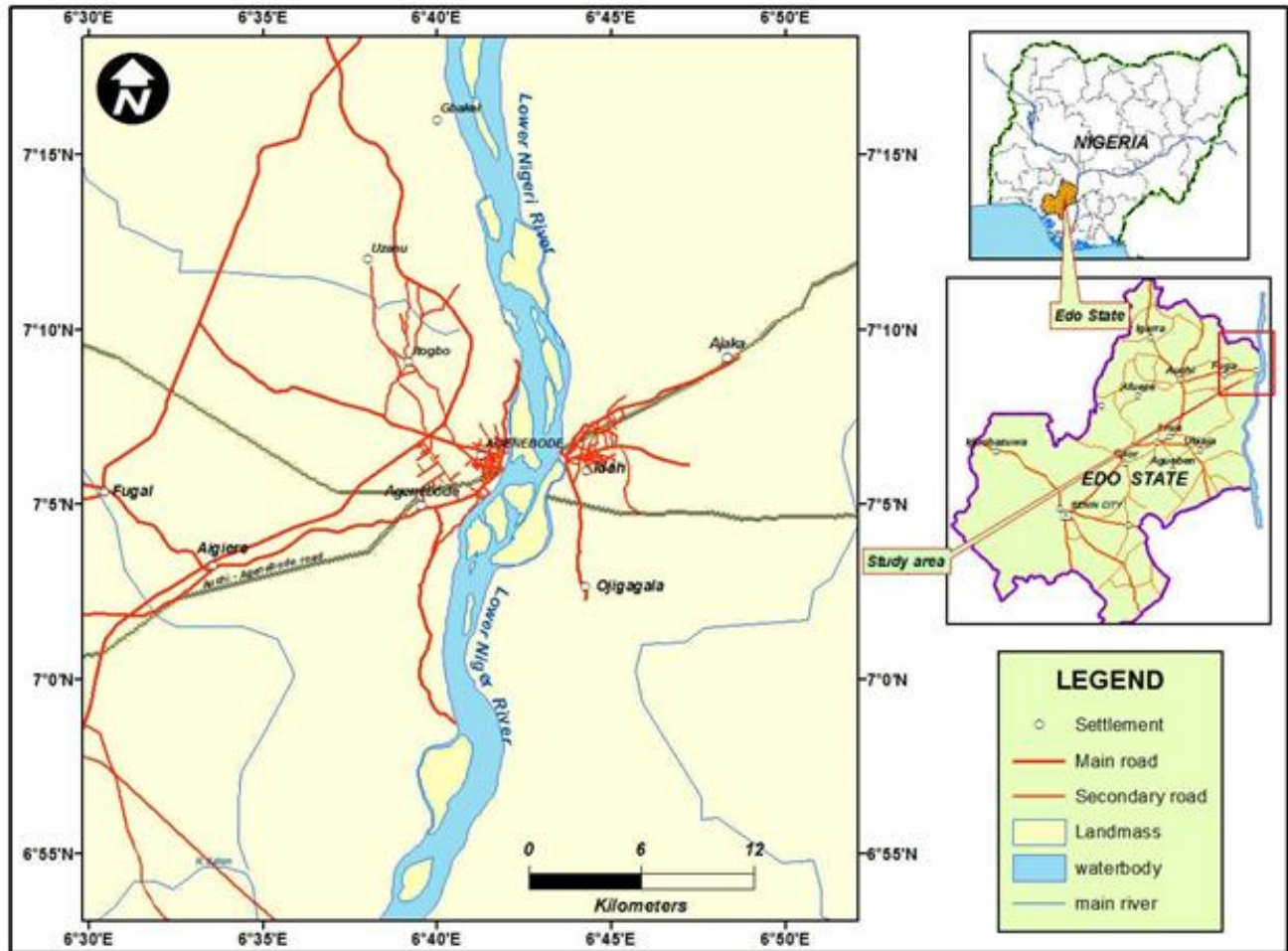


Figure 1. Map of Agenebode showing the study area.

Community Respiration (CR) = initial DO in dark bottle in mgL^{-1} (IDDO) – final DO in dark bottle in mgL^{-1} (FDDO)

Gross Primary Production (GPP) = O_2 consumed by respiration in mgL^{-1} (OR) + Net Oxygen Production in mgL^{-1} (NOP)

In converting the DO (mgL^{-1}) values to $\text{gC/m}^3/\text{h}$, the factor 0.375 (12/32) was used, and the values per hour were multiplied by 24 hours to obtain the productivity values per day (Michael, 1984).

Data analysis

Data collected during the period of this study were analysed using descriptive (means and standard deviations) and inferential statistics (one-way ANOVA and t-test) using Microsoft Excel and SAS (statistical analysis system). Pooled data were presented as seasonal and spatial mean variances at $P < 0.05$. Average (mean) values were separated with Turkey's honest significant difference (HSD) multiple range test.

RESULTS

The spatial and temporal variation in primary productivity (Gross Primary Productivity, Net Primary Productivity, and Community Respiration) obtained in the Lower River Niger is presented in Tables 1 and 2; and Figures 2 and 3.

Gross primary productivity

Gross Primary Productivity (GPP) ranged from 0.73 to 1.07 $\text{g/O}_2/\text{m}^3/\text{d}$. The mean values were 0.73 ± 0.03 , 0.89 ± 0.28 and 1.07 ± 0.25 $\text{g/O}_2/\text{m}^3/\text{d}$ for A1, A2 and A3 respectively (Table 1 and Figures 2). The grand mean value recorded for GPP was 0.897 ± 0.29 $\text{g/O}_2/\text{m}^3/\text{d}$. Seasonally, the higher (0.82 ± 0.06 $\text{g/O}_2/\text{m}^3/\text{d}$) value was obtained in the dry season than the wet season (0.44 ± 0.11 $\text{g/O}_2/\text{m}^3/\text{d}$). There was no significant difference seasonally (Table 2 and Figure 3).

Net primary productivity

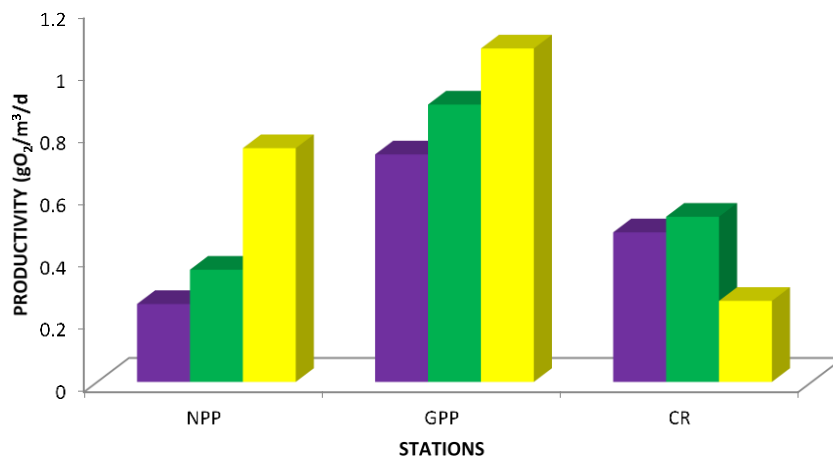
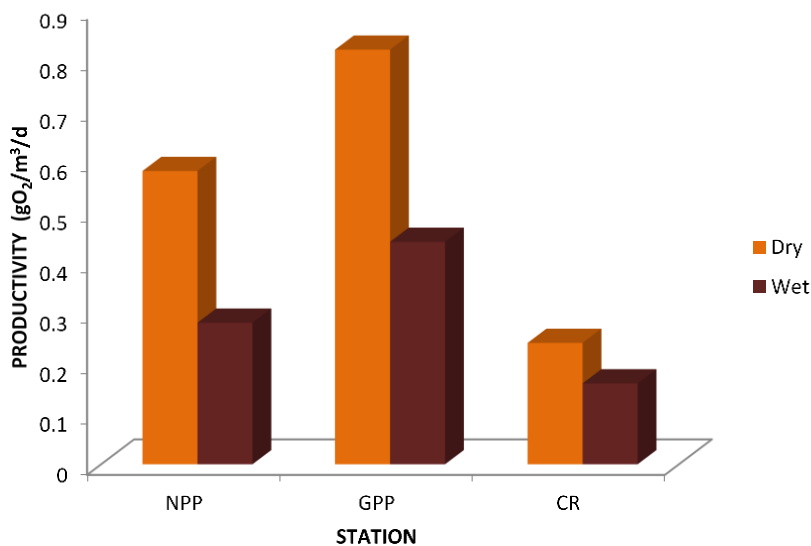
The mean Net Primary Productivity (NPP) ranged from

Table 1. Spatial variation of primary productivity of the Lower River Niger at Agenebode.

Parameters	A1	A2	A3	p-value
Net Primary Productivity (g/O ₂ /m ³ /d)	0.25±0.05 ^a	0.36 ±0.06 ^a	0.75±0.28 ^b	0.43
Gross Primary Productivity (g/O ₂ /m ³ /d)	0.73±0.03 ^a	0.89±0.28 ^a	1.07±0.25 ^b	0.63
Community Respiration (g/O ₂ /m ³ /d)	0.48 ±0.12 ^a	0.53±0.25 ^a	0.26±0.12 ^b	0.20

Table 2. Seasonal variation distribution of primary productivity of the Lower River Niger at Agenebode.

Parameters	Dry	Wet	p-value	Mean ± SD
Net Primary Productivity (g/O ₂ /m ³ /d)	0.58±0.06	0.28 ±0.06	0.18	0.43±0.21
Gross Primary Productivity (g/O ₂ /m ³ /d)	0.82±0.06	0.44±0.11	0.23	0.63±0.27
Community Respiration (g/O ₂ /m ³ /d)	0.24 ±0.28	0.16±0.12	0.03	0.20±0.06

**Figure 2.** Spatial variation of primary productivity in the Lower River Niger at Agenebode.**Figure 3.** Seasonal variation of mean primary productivity of the Lower River Niger at Agenebode.

0.25±0.05 g/O₂/m³/d in A1 to 0.75±0.28 g/O₂/m³/d in A3 with a spatial mean value of 0.45±0.23 g/O₂/m³/d as represented in Table 1 and Figure 2. There was no significant difference spatially. The value of NPP (0.58±0.06 g/O₂/m³/d) was higher in the dry season than in the wet season (0.28±0.06 g/O₂/m³/d); however, there was no significant difference seasonally (Table 2 and Figure 3).

Community respiration

The Community Respiration (CR) values recorded in Lower River Niger at Agenebode for A1, A2, and A3 zones were 0.48±0.12 g/O₂/m³/d, 0.53±0.25 g/O₂/m³/d, and 0.26±0.12 g/O₂/m³/d. The highest mean value (0.53±0.25 g/O₂/m³/d) was recorded in zone A2, whereas the lowest mean value (0.26±0.12 g/O₂/m³/d) was recorded in zone A3. The mean CR values (A1-A3) for the zones was 0.42±0.18 g/O₂/m³/d (Table 1 and Figure 2). However, there was no significant difference spatially.

Seasonally, the mean CR obtained for the dry season (0.24±0.28 g/O₂/m³/d) was higher in the dry season than the mean value of CR obtained in the wet season (0.16±0.12 g/O₂/m³/d). The seasonal mean CR value recorded was 0.20±0.06 g/O₂/m³/d (Table 2 and Figure 3). Seasonally, there was a significant difference in the CR of the Lower River Niger at Agenebode.

DISCUSSION

The gross primary productivity (GPP) of 1.07 g O₂ m⁻² d⁻¹ recorded in the Lower Niger River was relatively low compared with values reported for many Nigerian lakes and reservoirs. Recent studies, for example, reported mean GPP levels of 0.97 ± 0.43 g C m⁻² d⁻¹ in Erelu Reservoir, Oyo State (Kareem *et al.*, 2018), and higher productivity trends have been documented in parts of the Niger River Basin (Ogbue *et al.*, 2023), NIFFR Reservoir (3.17 gO₂m⁻²d⁻¹) (Bwala *et al.*, 2010) and Dandaru Lake with 1.23± 1.68 gC/m²/day (Ayoade and Izah, 2019). In contrast, GPP in the present study is still higher than values reported for some oligotrophic systems, such as those observed in portions of the Imo River, where low primary productivity was linked to nutrient limitation and high turbidity (Onweremadu *et al.*, 2010; Ayoade and Izah, 2019). These comparisons highlight the spatial heterogeneity of productivity within Nigerian inland waters.

The observed seasonal fluctuations in net primary productivity (NPP), GPP, and community respiration (CR) reflect the dynamic interplay of environmental conditions, with turbidity emerging as a key limiting factor. Elevated turbidity levels in the study area likely reduced light penetration, thereby constraining photosynthetic efficiency, even under high relative humidity and comparable nutrient levels to other Niger Delta ecosystems (Onweremadu *et al.*, 2010; Kareem *et al.*, 2018). This trend

aligns with broader findings in the Niger Basin, where precipitation, water availability, and evapotranspiration strongly regulate NPP over seasonal and interannual timescales (Ogbue *et al.*, 2023).

Overall, the similarity in NPP and CR trends relative to GPP suggests a relatively stable autotrophic community, with respiration accounting for a predictable portion of total production. These findings underscore how hydrological and optical factors—particularly turbidity—can act as dominant controls of productivity patterns in tropical river–reservoir systems.

Conclusion

The Primary productivity of Lower River Niger, Agenebode of 0.75 gO₂m⁻²d⁻¹ was relatively low compared to those of most inland water bodies in Nigeria due to the high relative humidity that is prevalent in the study area and high turbidity, caused by the anthropogenic activities observed around the river, which blankets off sunlight that is a major source for photosynthesis. This finding may portend negative implications for the fisheries of the river. Therefore, there is a need for adequate management of the river for sustainable productivity.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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