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Spatially Uniform Plankton Assemblages and A Temperature-Linked Zooplankton Gradient in a Tidal Peri-Urban River of The Niger Delta: The Egbelu Reach of The New Calabar River, Nigeria

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Abstract
Plankton respond quickly to changes in water quality and are widely used to assess rivers and estuaries. Even so, few Niger Delta studies have related plankton structure to environmental variables measured at the same places and times. We sampled phytoplankton and zooplankton at three stations on the Egbelu reach of the New Calabar River, Rivers State, Nigeria, every month from May to July 2026, and measured eleven physico-chemical variables alongside them. Salinity (0.45–1.88 ppt), conductivity and total dissolved solids differed among stations, while temperature (27.5–28.0 °C) and pH rose over the three months. The phytoplankton count came to 1,171 individuals in 19 taxa from four classes. Bacillariophyceae dominated (68.1%), followed by Cyanophyceae (23.4%), Chlorophyceae (6.3%) and Euglenophyceae (2.1%). Zooplankton numbered 1,124 individuals in 14 taxa: Copepoda (42.6%; five calanoid morphotypes), Cladocera (22.4%), Rotifera (20.2%) and tintinnid Protozoa (14.8%). Both assemblages were diverse and very even (phytoplankton H′ = 2.83–2.85, J′ = 0.96–0.97; zooplankton H′ = 2.60–2.61, J′ = 0.98–0.99), and Bray–Curtis similarity among stations was above 88%. For both groups, cluster analysis set Station 1 apart from Stations 2 and 3. In canonical correspondence analysis, temperature defined the first axis for both groups, but the model was significant only for zooplankton (52.8% of inertia constrained; p = 0.044), not for phytoplankton (p = 0.299). In the early rainy season, plankton composition in this reach followed temperature and sampling month more closely than it followed the spatial differences in water chemistry.

Keywords: *phytoplankton; zooplankton; canonical correspondence analysis; bioindicators; tidal river; Niger Delta*

1. Introduction

Phytoplankton and zooplankton form the base of aquatic food webs and turn over within days to weeks, so a change in their composition is often an early sign that water quality is shifting (Reynolds, 2006; Jeppesen et al., 2011). Phytoplankton respond directly to light, nutrients, mixing and salinity. Some groups, cyanobacteria above all, become more prominent as water warms and nutrient loads increase (Huisman et al., 2018). Zooplankton pick up these changes one step further up the food web, and their abundance and composition follow temperature closely enough for them to be widely regarded as sentinels of climate and environmental change (Richardson, 2008). Freshwater and estuarine biota now face pollution, habitat change and warming all at once, which makes fast-responding communities especially valuable for monitoring (Reid et al., 2019; Birk et al., 2020). Plankton data from tidal rivers are not easy to interpret. Salinity, turbidity and flow change with the tide and the season, and the organisms living there are adapted to this variability. The signal of human disturbance can therefore be hard to separate from natural fluctuation (Elliott & Quintino, 2007). Along the salinity gradient, the low-salinity zone is a transition where freshwater and marine taxa overlap, and the balance between them can shift quickly as discharge changes (Telesh & Khlebovich, 2010). A useful baseline, then, has to record when and where samples were taken and measure the environmental variables that might explain what is found. The New Calabar River is a tidal blackwater river in the eastern Niger Delta. It starts as a freshwater stream near Elele-Alimini, flows past the settlements of Aluu, Choba and Ogbogoro, and enters the Bonny estuary near Bakana (Dienye & Woke, 2015; Nwibani et al., 2025). Its middle and lower reaches receive abattoir waste, industrial and domestic effluent and urban runoff, and dredging and sand mining disturb them (Nwibani et al., 2025). Heavy metals have been found in its water, sediment and fish (Davies & Ekperusi, 2021). Around Ogbogoro, Imachrist et al. (2024) found a zooplankton community dominated by protozoans and copepods and reported poor conditions near a dredging site. Phytoplankton data for this part of the river are still scarce, few studies have analysed both plankton groups against the same measured variables, and no plankton study has yet been published for the Egbelu reach. We aimed to (i) describe how physico-chemical conditions in the Egbelu reach varied between stations and between months in the early rainy season; (ii) document the composition, abundance and diversity of its phytoplankton and zooplankton; (iii) assess how similar the plankton assemblages were from station to station; and (iv) find out which of the measured environmental variables best explained variation in plankton composition.

2. Methodology

2.1. Study area

Sampling was done on the Egbelu reach of the New Calabar River in Obio/Akpor Local Government Area, Rivers State, Nigeria (Fig. 1). The climate is humid tropical, with a long rainy season from about March to October and annual rainfall that often exceeds 2,000 mm. The reach is tidal and oligohaline, and houses, small landing sites and secondary vegetation line its banks. We fixed three stations with a handheld GPS receiver so that they covered the gradient of tidal influence and human activity along the reach: Station 1 (upstream; 4.8499° N, 6.9238° E), Station 2 (midstream; 4.8470° N, 6.9296° E) and Station 3 (downstream; 4.8438° N, 6.9355° E). Stations 1 and 2 were about 0.72 km apart and Stations 2 and 3 about 0.74 km apart, so the stations covered roughly 1.5 km of river.

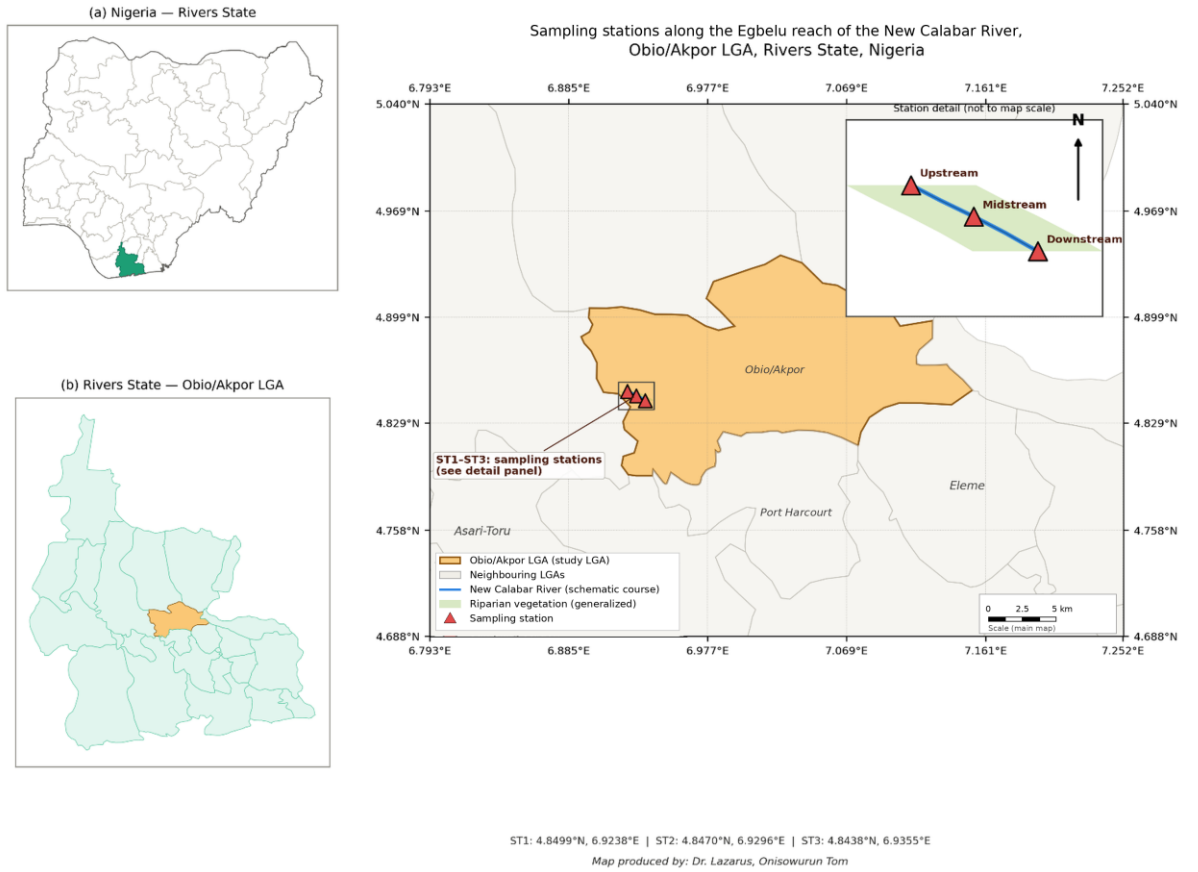


Fig. 1. Location of the study area: (a) Nigeria, showing Rivers State; (b) Rivers State, showing Obio/Akpor Local Government Area; (c) the Egbelu reach of the New Calabar River with sampling Stations 1–3 (ST1–ST3). The station detail panel is not drawn to the map scale.

2.2. Sampling design

Each station was sampled once a month in May, June and July 2026. On every visit we collected water for physico-chemical analysis in triplicate and, at the same time, took three replicate plankton tows. This gave nine sampling events (three stations × three months) for the multivariate analyses. The physico-chemical data come from a single field campaign that also served companion studies of the fish and benthic macroinvertebrates of the reach (Wala et al., in preparation), and we report them in full here so that the paper can stand alone.

2.3. Physico-chemical analysis

Temperature, pH, dissolved oxygen (DO) and electrical conductivity (EC) were measured on site with a calibrated multi-parameter meter (APHA, 2017). Salinity was read with a hand-held refractometer. Total dissolved solids (TDS) were taken from the conductivity meter and checked gravimetrically. Turbidity was measured nephelometrically (APHA, 2017, Method 2130 B), and current velocity with a portable flow meter, with the float method used as a check. Nitrate was determined by cadmium reduction (APHA, 2017, Method 4500-NO_3^- E) and phosphate by the ascorbic acid method (Murphy & Riley, 1962), both read on a UV–visible spectrophotometer. BOD_5 was measured after five days of incubation using the azide modification of the Winkler method (APHA, 2017).

2.4. Plankton collection and analysis

At each station and on each visit, plankton were collected with three horizontal tows just below the surface, each covering about 10 m. We used nets with a 30 cm mouth diameter (mouth area

0.0707 m^2): a 20–25 µm mesh net for phytoplankton and a 55–63 µm mesh net for zooplankton. Assuming complete filtration, the volume filtered per tow was estimated as mouth area × tow distance (0.71 m^3), which gives 2.12 m^3 per station per visit and 6.36 m^3 per station over the three months. Phytoplankton concentrates were preserved in Lugol's iodine, with 4% formalin as a back-up fixative, and zooplankton in 4% buffered formalin (APHA, 2017).

In the laboratory, phytoplankton were counted in a Sedgewick–Rafter chamber under a compound microscope (APHA, 2017) and identified with Bellinger and Sigee (2015). For zooplankton, a measured subsample of the concentrated sample was examined in a counting chamber under the microscope, and taxa were identified with Edmondson (1959) and Boltovskoy (1999). Calanoid copepods that could not be confirmed to species with keys suited to West African waters were recorded as numbered morphotypes (Calanoida sp. 1–5), and one brachionid rotifer was recorded at family level. For each station, counts from the three tows and three-monthly visits were pooled, and percentage relative abundance was calculated as (N_i / N_{total}) × 100 for every taxon and taxonomic group, both by station and for all stations together. Nets of 20–25 µm mesh retain only part of the phytoplankton, so we report phytoplankton composition as relative abundance rather than cell density.

2.5. Data analysis

We tested differences in each physico-chemical variable among stations and among months with one-way ANOVA, followed by Tukey's honestly significant difference test where $p < 0.05$ (Tukey, 1949). Some variables gave identical readings in every replicate and month at a station; because their within-station variance was zero, they were not tested among stations. Diversity at each station and for the pooled data was described with taxon richness (S), the Shannon–Wiener index $H' = -\Sigma\, p_i \ln p_i$ (Shannon & Weaver, 1949), Simpson's index of diversity $1 - D$, where $D = \Sigma\, p_i^2$ (Simpson, 1949), Pielou's evenness $J' = H'/\ln S$ (Pielou, 1966) and Margalef's richness $d = (S - 1)/\ln N$ (Margalef, 1958).

To compare composition among stations, we calculated Bray–Curtis dissimilarity on untransformed abundances for each assemblage (Bray & Curtis, 1957) and then clustered the stations hierarchically with the unweighted pair group method with arithmetic mean (UPGMA; Sneath & Sokal, 1973; Legendre & Legendre, 2012).

We used canonical correspondence analysis (CCA; ter Braak, 1986) to look at how plankton composition related to the environment, running it separately for phytoplankton and zooplankton on the nine station × month samples. Several physico-chemical variables did not vary within stations and were therefore strongly collinear. After screening the variables with variance inflation factors, we kept temperature, salinity and pH as explanatory variables (Legendre & Legendre, 2012; ter Braak & Verdonschot, 1995). The significance of the constrained ordination was tested with a Monte Carlo permutation test on the trace statistic (999 unrestricted permutations). With nine samples and three constraints, we treated the CCA as exploratory. Analyses were run in PAST (Hammer et al., 2001) and in R version 4.3 (R Core Team, 2023) with the vegan package (Oksanen et al., 2022), and $p < 0.05$ was taken as significant.

3. Results

3.1. Physico-chemical conditions

Throughout the study the water was warm (27.50–28.00 °C), close to neutral (pH 7.03–7.15) and well oxygenated (DO 6.50–6.80 mg L^{-1}) (Table 1). Only two variables changed over time. Temperature rose from 27.50 °C in May to 28.00 °C in July ($p < 0.001$), with July warmer than both earlier months. pH went up from 7.03 to 7.13 ($p = 0.001$), but only May and July differed from each other (Tukey HSD). Neither variable differed much among stations, although pH was a little higher at Station 2.

Salinity, EC and TDS stayed steady from month to month but differed significantly among stations ($p < 0.001$). Station 1 was the least saline (0.45 ppt) and Station 2 the most saline (1.88 ppt). EC and TDS, by contrast, were highest at Station 1 (9,700 µS cm^{-1}; 4,850 mg L^{-1}) and similar at Stations 2 and 3. Station 2 also had the highest turbidity (18.00 NTU), current velocity (0.35 m s^{-1}), nitrate (0.90 mg L^{-1}), phosphate (0.25 mg L^{-1}) and BOD_5 (2.80 mg L^{-1}), while Station 1 had the lowest. These readings, like those for DO, were identical in every replicate and month at a given station, so we report the differences descriptively rather than testing them. Monthly trends appear in Appendix Fig. A1.

Table 1. Spatial (station) and temporal (month) variation in physico-chemical parameters of the Egbelu reach of the New Calabar River, May–July 2026.

Parameter	Station (spatial)				Month (temporal)			
	Station 1	Station 2	Station 3	*p*	May	June	July	*p*
Temperature (°C)	27.77 ± 0.22[a]	27.67 ± 0.25[a]	27.67 ± 0.25[a]	0.600	27.50 ± 0.00[a]	27.60 ± 0.15[a]	28.00 ± 0.00[b]	<0.001
Salinity (ppt)	0.45 ± 0.04[a]	1.88 ± 0.07[b]	1.68 ± 0.07[c]	<0.001	1.27 ± 0.66	1.35 ± 0.68	1.40 ± 0.68	0.914
pH	7.05 ± 0.04[a]	7.15 ± 0.04[b]	7.05 ± 0.04[a]	<0.001	7.03 ± 0.05[a]	7.08 ± 0.05[ab]	7.13 ± 0.05[b]	0.001
EC (µS cm^{-1})	9700 ± 173[a]	4133 ± 109[b]	4200 ± 87[b]	<0.001	5867 ± 2725	6017 ± 2763	6150 ± 2813	0.977
TDS (mg L^{-1})	4850 ± 87[a]	2063 ± 52[b]	2073 ± 22[b]	<0.001	2933 ± 1363	3007 ± 1383	3047 ± 1428	0.985
DO (mg L^{-1})	6.50 ± 0.00	6.80 ± 0.00	6.70 ± 0.00	n.t.	6.67 ± 0.13	6.67 ± 0.13	6.67 ± 0.13	1.000
Turbidity (NTU)	15.00 ± 0.00	18.00 ± 0.00	16.00 ± 0.00	n.t.	16.33 ± 1.32	16.33 ± 1.32	16.33 ± 1.32	1.000
Current velocity (m s^{-1})	0.30 ± 0.00	0.35 ± 0.00	0.32 ± 0.00	n.t.	0.32 ± 0.02	0.32 ± 0.02	0.32 ± 0.02	1.000
Nitrate (mg L^{-1})	0.80 ± 0.00	0.90 ± 0.00	0.85 ± 0.00	n.t.	0.85 ± 0.04	0.85 ± 0.04	0.85 ± 0.04	1.000
Phosphate (mg L^{-1})	0.20 ± 0.00	0.25 ± 0.00	0.22 ± 0.00	n.t.	0.22 ± 0.02	0.22 ± 0.02	0.22 ± 0.02	1.000
BOD_5 (mg L^{-1})	2.50 ± 0.00	2.80 ± 0.00	2.60 ± 0.00	n.t.	2.63 ± 0.13	2.63 ± 0.13	2.63 ± 0.13	1.000

Values are mean ± SD ($n = 9$ per station: three months × triplicate samples; $n = 9$ per month: three stations × triplicate samples). *p* values are from one-way ANOVA. Within the station columns and within the month columns, means sharing a superscript letter do not differ significantly (Tukey HSD, $\alpha = 0.05$); monthly letters are shown only for the two variables with a significant monthly effect. n.t., not tested: readings were identical in every replicate and month at each station, so within-station variance was zero and a station ANOVA is undefined; these station values are reported descriptively. EC, electrical conductivity; TDS, total dissolved solids; DO, dissolved oxygen; BOD_5, five-day biochemical oxygen demand.

3.2. Phytoplankton composition and abundance

We counted 1,171 phytoplankton individuals belonging to 19 taxa in four classes (Table 2). Bacillariophyceae (diatoms) dominated, with ten taxa and 68.1% of all individuals. Cyanophyceae came next (six taxa; 23.4%), then Chlorophyceae (two taxa; 6.3%) and Euglenophyceae (one taxon; 2.1%). Abundance fell from Station 1 (420) to Station 2 (387) and Station 3 (364). Overall, the most abundant taxa were *Cymbella cymbiformis* (9.5%), *Coscinodiscus centralis* (8.5%), *Cyclotella operculata* (8.4%), *Cymbella affinis* (7.9%) and *Achnanthes affinis* (7.9%), and the least abundant were *Lepocinclis acus* (2.1%) and *Nitzschia angulata* (2.6%). The proportions of the four classes were much the same at every station (Fig. 2), but some taxa showed clear spatial trends. Cyanophyceae made up a slightly smaller share at Station 3 (21.7%) than at Stations 1 and 2 (24.0–24.3%), mostly because *Dolichospermum flos-aquae* and *Aphanothece microscopica* were most abundant at Station 1. *Lepocinclis acus* and *Coscinodiscus lacustris* also peaked at Station 1, whereas *Cymbella affinis* became more abundant from Station 1 to Station 3.

Table 2. Composition, abundance (*N*) and percentage relative abundance (%) of phytoplankton at three stations on the Egbelu reach of the New Calabar River (May–July 2026 pooled).

Group / taxon	Station 1		Station 2		Station 3		Pooled	
	N	**%**	***N***	**%**	***N***	**%**	***N***	**%**
Bacillariophyceae								
Achnanthes affinis	30	7.1	35	9.0	27	7.4	92	7.9
Aulacoseira distans	28	6.7	25	6.5	21	5.8	74	6.3
Coscinodiscus centralis	40	9.5	27	7.0	32	8.8	99	8.5
Coscinodiscus lacustris	32	7.6	18	4.7	16	4.4	66	5.6
Cyclotella operculata	32	7.6	33	8.5	33	9.1	98	8.4
Cyclotella striata	31	7.4	29	7.5	24	6.6	84	7.2
Cylindrotheca closterium	16	3.8	17	4.4	18	4.9	51	4.4
Cymbella affinis	26	6.2	32	8.3	35	9.6	93	7.9
Cymbella cymbiformis	36	8.6	39	10.1	36	9.9	111	9.5
Nitzschia angulata	9	2.1	12	3.1	9	2.5	30	2.6
Subtotal	*280*	*66.7*	*267*	*69.0*	*251*	*69.0*	*798*	*68.1*
Chlorophyceae								
Closterium gracile	15	3.6	12	3.1	17	4.7	44	3.8
Closterium lunula	11	2.6	7	1.8	12	3.3	30	2.6
Subtotal	*26*	*6.2*	*19*	*4.9*	*29*	*8.0*	*74*	*6.3*
Cyanophyceae								
Aphanothece microscopica	24	5.7	17	4.4	13	3.6	54	4.6
Dolichospermum flos-aquae	25	6.0	16	4.1	15	4.1	56	4.8
Gloeocapsa magma	18	4.3	18	4.7	16	4.4	52	4.4
Gloeocapsa rupestris	13	3.1	15	3.9	14	3.8	42	3.6
Oscillatoria limosa	9	2.1	17	4.4	9	2.5	35	3.0

Group / taxon	Station 1		Station 2		Station 3		Pooled	
	N	%	*N*	%	*N*	%	*N*	%
Oscillatoria sancta	12	2.9	11	2.8	12	3.3	35	3.0
Subtotal	*101*	*24.0*	*94*	*24.3*	*79*	*21.7*	*274*	*23.4*
Euglenophyceae								
Lepocinclis acus	13	3.1	7	1.8	5	1.4	25	2.1
Total	**420**	**100**	**387**	**100**	**364**	**100**	**1171**	**100**

N, number of individuals counted over the three sampling months. Percentages are relative to the station or pooled total. Names follow AlgaeBase: *Aulacoseira distans* (syn. *Melosira distans*), *Cylindrotheca closterium* (syn. *Nitzschia closterium*), *Dolichospermum flos-aquae* (syn. *Anabaena flos-aquae*) and *Lepocinclis acus* (syn. *Euglena acus*).

3.3. Zooplankton composition and abundance

The zooplankton count came to 1,124 individuals in 14 taxa from four groups (Table 3). Copepoda, represented by five calanoid morphotypes, made up 42.6% of individuals. They were followed by Cladocera (three taxa; 22.4%), Rotifera (four taxa; 20.2%) and tintinnid Protozoa (two taxa; 14.8%). Station totals were close (369–385 individuals). Calanoida sp. 2 was the most abundant taxon overall (10.4%), ahead of Calanoida sp. 1 (8.5%) and *Macrothrix rosea* (8.3%). *Keratella quadrata* was the least abundant (3.3%), and it was twice as common at Station 2 as at Stations 1 and 3. Copepods made up the largest share at Station 2 (45.3%), where Calanoida sp. 5 was most abundant. Cladocera peaked at Station 3 (23.6%), largely because of *Penilia avirostris*, and Protozoa were best represented at Station 1 (16.2%). Rotifers contributed an almost constant share at every station (19.7–20.5%) (Fig. 2).

Table 3. Composition, abundance (*N*) and percentage relative abundance (%) of zooplankton at three stations on the Egbelu reach of the New Calabar River (May–July 2026 pooled).

Group / taxon	Station 1		Station 2		Station 3		Pooled	
	N	%	*N*	%	*N*	%	*N*	%
Copepoda								
Calanoida sp. 1	36	9.7	34	9.2	26	6.8	96	8.5
Calanoida sp. 2	34	9.2	41	11.1	42	10.9	117	10.4
Calanoida sp. 3	30	8.1	29	7.9	30	7.8	89	7.9
Calanoida sp. 4	26	7.0	29	7.9	33	8.6	88	7.8
Calanoida sp. 5	24	6.5	34	9.2	31	8.1	89	7.9
Subtotal	*150*	*40.5*	*167*	*45.3*	*162*	*42.1*	*479*	*42.6*
Cladocera								
Alonella sp.	25	6.8	23	6.2	21	5.5	69	6.1
Macrothrix rosea	34	9.2	27	7.3	32	8.3	93	8.3
Penilia avirostris	25	6.8	27	7.3	38	9.9	90	8.0
Subtotal	*84*	*22.7*	*77*	*20.9*	*91*	*23.6*	*252*	*22.4*
Rotifera								
Brachionus caudatus	24	6.5	18	4.9	21	5.5	63	5.6
Euchlanis triquetra	21	5.7	20	5.4	23	6.0	64	5.7
Brachionidae sp.	22	5.9	19	5.1	22	5.7	63	5.6

Group / taxon	Station 1		Station 2		Station 3		Pooled	
	N	%	*N*	%	*N*	%	*N*	%
Keratella quadrata	9	2.4	18	4.9	10	2.6	37	3.3
Subtotal	*76*	*20.5*	*75*	*20.3*	*76*	*19.7*	*227*	*20.2*
Protozoa (Ciliophora)								
Tintinnopsis senensis	31	8.4	24	6.5	30	7.8	85	7.6
Tintinnopsis wangi	29	7.8	26	7.0	26	6.8	81	7.2
Subtotal	*60*	*16.2*	*50*	*13.6*	*56*	*14.5*	*166*	*14.8*
Total	**370**	**100**	**369**	**100**	**385**	**100**	**1124**	**100**

N, number of individuals counted over the three sampling months. Percentages are relative to the station or pooled total. Calanoid copepods are reported as morphotypes and one rotifer at family level because species-level identifications could not be confirmed with keys appropriate to the region (Section 2.4).

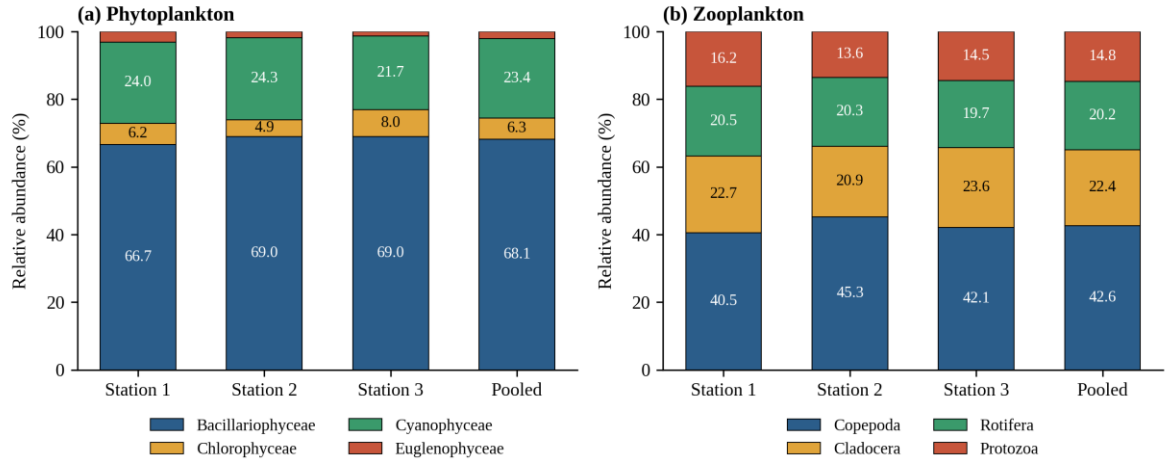


Fig. 2. Percentage relative abundance of the major taxonomic groups of (a) phytoplankton and (b) zooplankton at Stations 1–3 and for all stations pooled.

3.4. Diversity and similarity among stations

Both assemblages were diverse and very even (Table 4). Every one of the 19 phytoplankton taxa and 14 zooplankton taxa was found at every station. For phytoplankton, H′ ranged only from 2.83 to 2.85, J′ from 0.96 to 0.97 and Margalef's *d* from 2.98 to 3.05. For zooplankton, H′ was 2.60–2.61 and J′ 0.98–0.99, close to the theoretical maximum for 14 taxa. Phytoplankton diversity and evenness were marginally highest at Station 1, which also had the largest count. Bray–Curtis similarity among stations ranged from 88.7% to 91.6% for phytoplankton and from 91.5% to 92.3% for zooplankton. Within this narrow range, the cluster analysis grouped Stations 2 and 3 together for both assemblages and joined Station 1 to them at a higher level of dissimilarity (Fig. 3). Station 1 stood apart more clearly for phytoplankton (Bray–Curtis dissimilarity of 0.084 between Stations 2 and 3, against 0.113 between Station 1 and both of them) than for zooplankton (0.077 versus 0.083).

Table 4. Diversity indices of phytoplankton and zooplankton assemblages at three stations on the Egbelu reach of the New Calabar River.

Assemblage / station	*N*	*S*	H′	1 − *D*	J′	*d*
Phytoplankton						
Station 1	420	19	2.85	0.94	0.97	2.98
Station 2	387	19	2.84	0.94	0.96	3.02
Station 3	364	19	2.83	0.94	0.96	3.05
Pooled	1171	19	2.85	0.94	0.97	2.55
Zooplankton						
Station 1	370	14	2.60	0.92	0.99	2.20
Station 2	369	14	2.61	0.92	0.99	2.20
Station 3	385	14	2.60	0.92	0.98	2.18
Pooled	1124	14	2.61	0.92	0.99	1.85

N, total abundance; *S*, taxon richness; H′, Shannon–Wiener index (natural log); 1 − *D*, Simpson's index of diversity; J′, Pielou's evenness; *d*, Margalef's richness.

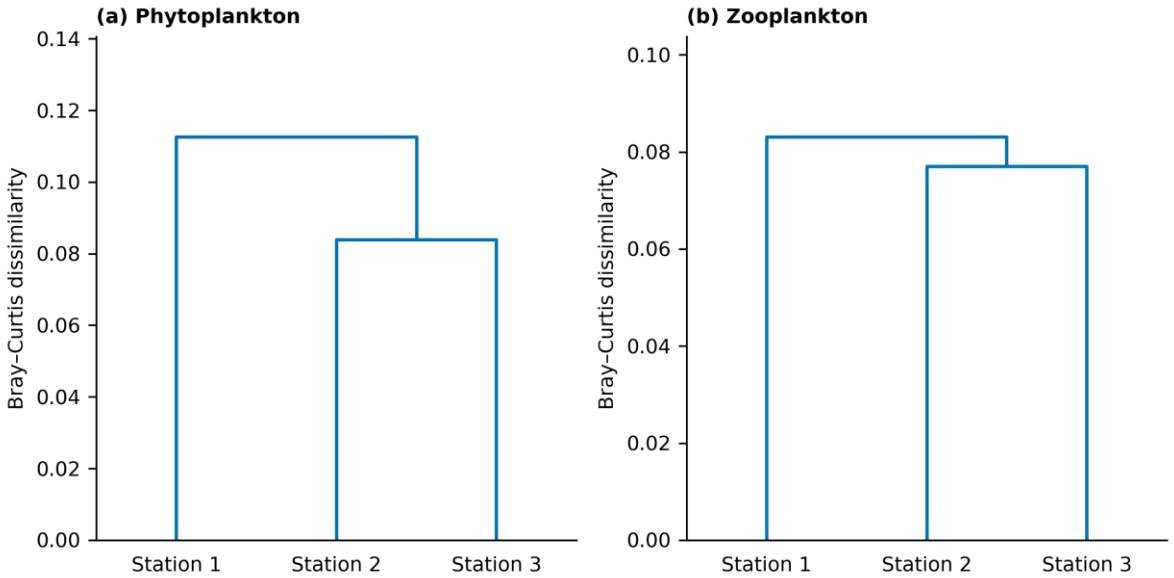


Fig. 3. UPGMA dendrograms based on Bray–Curtis dissimilarity of (a) phytoplankton and (b) zooplankton composition at the three sampling stations.

3.5. Relationships with environmental variables

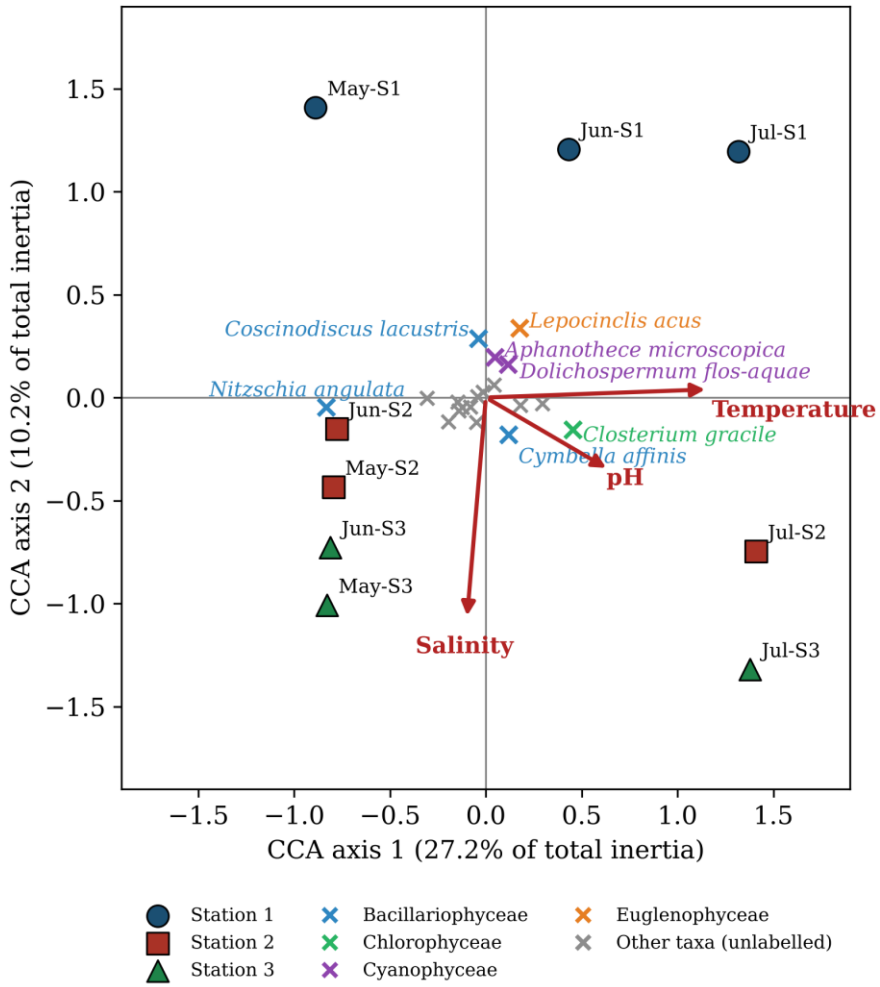
For phytoplankton, the three constrained axes together explained 43.0% of total inertia (Table 5), but the model was not significant (p = 0.299). Axis 1 (27.2%) was almost perfectly correlated with temperature (r = 0.999) and separated the warmer July samples from those taken in May and June (Fig. 4a). Axis 2 (10.2%) was a salinity axis (r = −0.925). It placed the three Station 1 samples at the top of the plot, away from the more saline samples from Stations 2 and 3. pH loaded mainly on axis 3 (r = 0.775). *Lepocinclis acus*, *Dolichospermum flos-aquae*, *Aphanothece microscopica* and *Coscinodiscus lacustris* sat towards the low-salinity end of axis 2, in line with their higher abundance at Station 1, while *Nitzschia angulata* was associated with the cooler, earlier samples. The zooplankton model was significant (p = 0.044), and its constrained axes explained 52.8% of total inertia (Table 5). Temperature again dominated axis 1 (33.7%; r = −0.901), placing the July samples from Stations 1 and 3 at the warm end of the gradient (Fig. 4b). Axis 2 (10.1%) was defined by pH (r = −0.979) and separated the Station 2

samples, which had the highest pH, from the others. Salinity was linked mainly with axis 3 (r = −0.844). *Keratella quadrata* was associated with the cooler May–June samples from Station 2. Most other taxa sat near the centre of the ordination, which is to be expected when every taxon occurs in every sample.

Table 5. Eigenvalues, variance explained and biplot correlations of physico-chemical variables with the canonical axes in CCA of phytoplankton and zooplankton.

	Axis 1	**Axis 2**	**Axis 3**
Phytoplankton			
Eigenvalue	0.0425	0.0160	0.0088
Inertia explained (%)	27.20	10.21	5.62
Cumulative (%)	27.20	37.42	43.04
Temperature	**0.999**	0.034	−0.024
Salinity	−0.085	**−0.925**	0.370
pH	0.555	−0.302	**0.775**
Zooplankton			
Eigenvalue	0.0270	0.0081	0.0072
Inertia explained (%)	33.67	10.08	9.03
Cumulative (%)	33.67	43.75	52.78
Temperature	**−0.901**	−0.292	0.321
Salinity	0.084	−0.530	**−0.844**
pH	−0.203	**−0.979**	0.016

Phytoplankton: total inertia = 0.1562; permutation test on the trace (999 permutations), p = 0.299. Zooplankton: total inertia = 0.0802; p = 0.044. Correlations ≥ |0.7| are shown in bold.


May-S1
Jun-S1
Jul-S1
Coscinodiscus lacustris
Lepocinclis acus
Aphanothece microscopica
Dolichospermum flos-aquae
Nitzschia angulata
Jun-S2
Temperature
Closterium gracile
Cymbella affinis
pH
May-S2
Jun-S3
Jul-S2
May-S3
Salinity
Jul-S3
CCA axis 2 (10.2% of total inertia)
CCA axis 1 (27.2% of total inertia)
Station 1
Station 2
Station 3
Bacillariophyceae
Chlorophyceae
Cyanophyceae
Euglenophyceae
Other taxa (unlabelled)

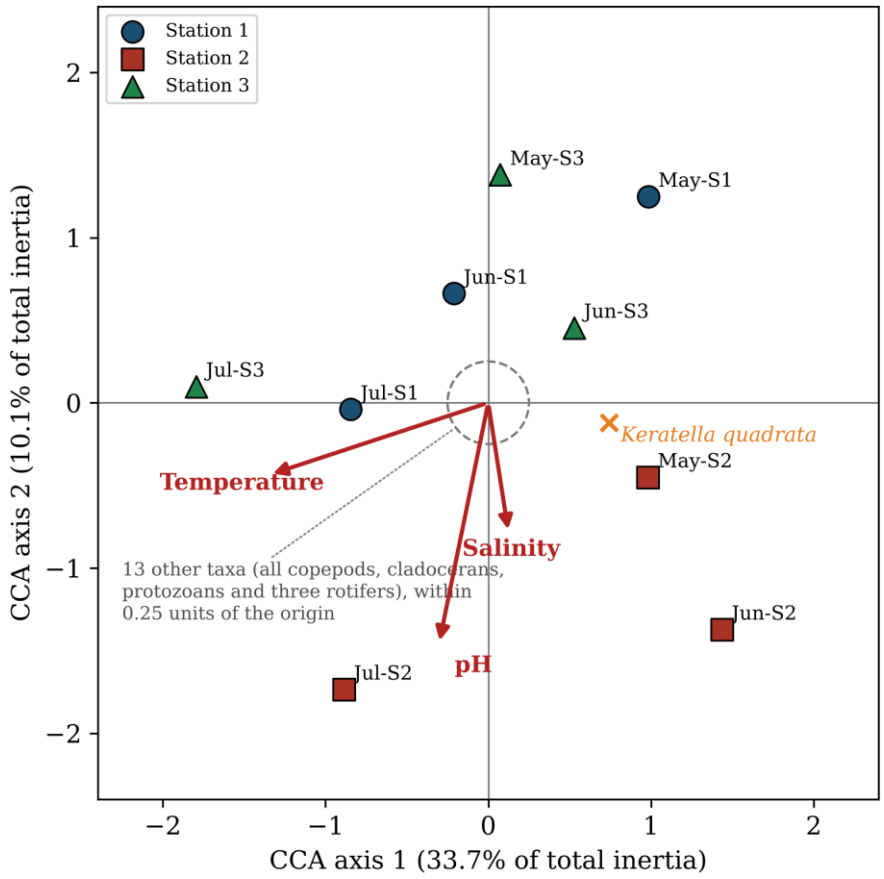


Fig. 4. CCA biplots of (a, upper) phytoplankton and (b, lower) zooplankton showing station × month samples (symbols), physico-chemical variables (arrows) and taxa (crosses). For legibility, only taxa lying away from the origin and discussed in the text are labelled and coloured by group; in (a) the remaining phytoplankton taxa are shown as grey crosses, and in (b) the remaining 13 zooplankton taxa lay within the dashed circle (0.25 units of the origin). Arrows are biplot correlations scaled for display. Axis labels give the percentage of total inertia explained.

4. Discussion

4.1. Environmental setting

The physico-chemical data describe a warm, oxygenated and only moderately enriched reach in the early rainy season. Dissolved oxygen stayed above 6.5 mg L^{-1} and BOD_5 below 3 mg L^{-1}, and nitrate and phosphate were lower than the values Nwibani et al. (2025) recorded further upstream. Salinity put the reach firmly in the oligohaline zone, below the 5–8 salinity range that marks the main transition between freshwater and marine biota (Telesh & Khlebovich, 2010). Conductivity and dissolved solids, however, were high, of the same order as those reported near Ogbogoro by Imachrist et al. (2024). That Station 1 combined the lowest salinity with the highest conductivity suggests an extra, non-marine source of ions near that station, such as effluent, leachate or groundwater inflow. Measurement limits may also play a part. Salinities below about 2 are close to the resolution of hand-held refractometers, whereas a conductivity of 9,700 µS cm^{-1} would equal a practical salinity of about 5 if it came from sea salts alone. This reading is therefore tentative and should be checked with measurements of major ions and conductivity-based salinity.

4.2. Phytoplankton

Diatoms usually dominate in turbid, well-mixed tidal rivers, where light is limited and the tide stirs the water column regularly (Reynolds, 2006). Centric genera such as *Coscinodiscus*, *Cyclotella* and *Aulacoseira* do well under these conditions, and pennate diatoms such as *Cymbella* and *Achnanthes* are often lifted from the bed into the water in shallow, flowing reaches. The steady rise in *Cymbella affinis* from Station 1 to Station 3 may reflect differences in substrate or flow along the reach. Cyanobacteria were the second most abundant group, accounting for nearly a quarter of all individuals. *Dolichospermum flos-aquae* and the two *Oscillatoria* species belong to genera that include bloom-forming and potentially toxic taxa, and cyanobacteria in general gain ground as water temperature and nutrient supply rise (Huisman et al., 2018). Nutrient levels were modest and we saw no bloom, so these data do not point to a cyanobacterial problem. They do, however, give a baseline against which future increases can be measured. Euglenoids, which tend to be favoured by organic enrichment (Bellinger & Sigee, 2015), were rare overall but most frequent at Station 1. Taken together with the high conductivity there, this suggests that Station 1 may receive a local input that deserves a closer look. With only nine samples and little variation in composition, it is not surprising that the phytoplankton CCA was not significant. The ordination was still informative. Its first axis followed temperature and sampling month, and its second axis separated the low-salinity Station 1 from the others, matching the cluster analysis. A longer time series would allow both gradients to be tested more rigorously.

4.3. Zooplankton

A zooplankton community led by copepods, with sizeable contributions from cladocerans and rotifers, is what one would expect in a low-salinity tidal reach where freshwater and estuarine taxa live side by side. It differs from the protozoan-dominated assemblage that Imachrist et al. (2024) described near Ogbogoro, where Protozoa made up 48% and Copepoda 29% in the same months of 2020. Differences in mesh size, counting method, station position and year could all contribute to this contrast, and the two data sets are better treated as complementary than as directly comparable. The zooplankton CCA was significant, though only modestly so (p = 0.044) for nine samples, and temperature was the strongest single gradient. Zooplankton development, reproduction and seasonal succession are closely tied to temperature (Richardson, 2008), and the 0.5 °C rise between May and July matched a clear shift in sample position along the first axis. Rotifers such as *Keratella* and *Brachionus* are often associated with productive or enriched waters (Jeppesen et al., 2011), but here rotifer abundance was almost the same at every station and offers no evidence of local enrichment. Over three months, temperature and month were almost perfectly confounded. The temperature effect is therefore best read as a seasonal effect that cannot yet be separated from other rainy-season changes, including discharge and turbidity.

4.4. Spatial uniformity of the plankton

Both assemblages were uniform across stations. Every taxon occurred everywhere, evenness was close to its maximum, and Bray–Curtis similarity was above 88%. The clear differences in salinity, conductivity, turbidity and nutrients among stations thus left only a faint mark on plankton composition. Tidal mixing is the likely reason. The stations are within 1.5 km of one another and the tide carries plankton up and down the reach twice a day, so each station is sampling water that has only recently passed the others. Pooling three tows and three months at each station also raises the chance of recording every taxon everywhere. In transitional waters, community indices can stay high and stable even where environmental differences are real, which makes them blunt tools for picking up local impacts (Elliott & Quintino, 2007). For

monitoring this reach, indicator taxa, densities and trait-based measures are likely to be more sensitive than diversity indices on their own.

4.5. Limitations

The study covered three months of one rainy season at three stations, so the multivariate analyses rest on nine samples and should be seen as exploratory. Abundances are given as subsample counts and relative abundances rather than densities per unit volume, which limits comparison with other studies, and filtered volumes were estimated from net mouth area and tow distance without a flowmeter. The calanoid copepods could be resolved only to morphotype level, and checking these and other identifications against voucher material and keys for West African waters would strengthen the indicator interpretation. Future work should use a flowmeter, record subsample fractions so that densities can be estimated, collect whole-water phytoplankton samples for cell densities, extend sampling into the dry season, and add chlorophyll-*a* and major ions to the variables measured.

5. Conclusion

In the early rainy season of 2026, the Egbelu reach of the New Calabar River supported diverse and even plankton assemblages dominated by diatoms and copepods. Although water chemistry differed clearly from station to station, plankton composition was almost the same at all three, and the main compositional gradient followed temperature and sampling month. That gradient was significant for zooplankton but not for phytoplankton. These results give the first plankton baseline for the reach. They also suggest that monitoring should cover the full seasonal cycle and rely on indicator taxa and densities rather than on diversity indices alone.

Declarations

Author contributions. All authors contributed to the conception and design of the study, field sampling, laboratory work, data analysis and preparation of the manuscript. All authors read and approved the final version.

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Declaration of competing interest. The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability. The data supporting this study are available from the corresponding author on reasonable request.

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Appendix

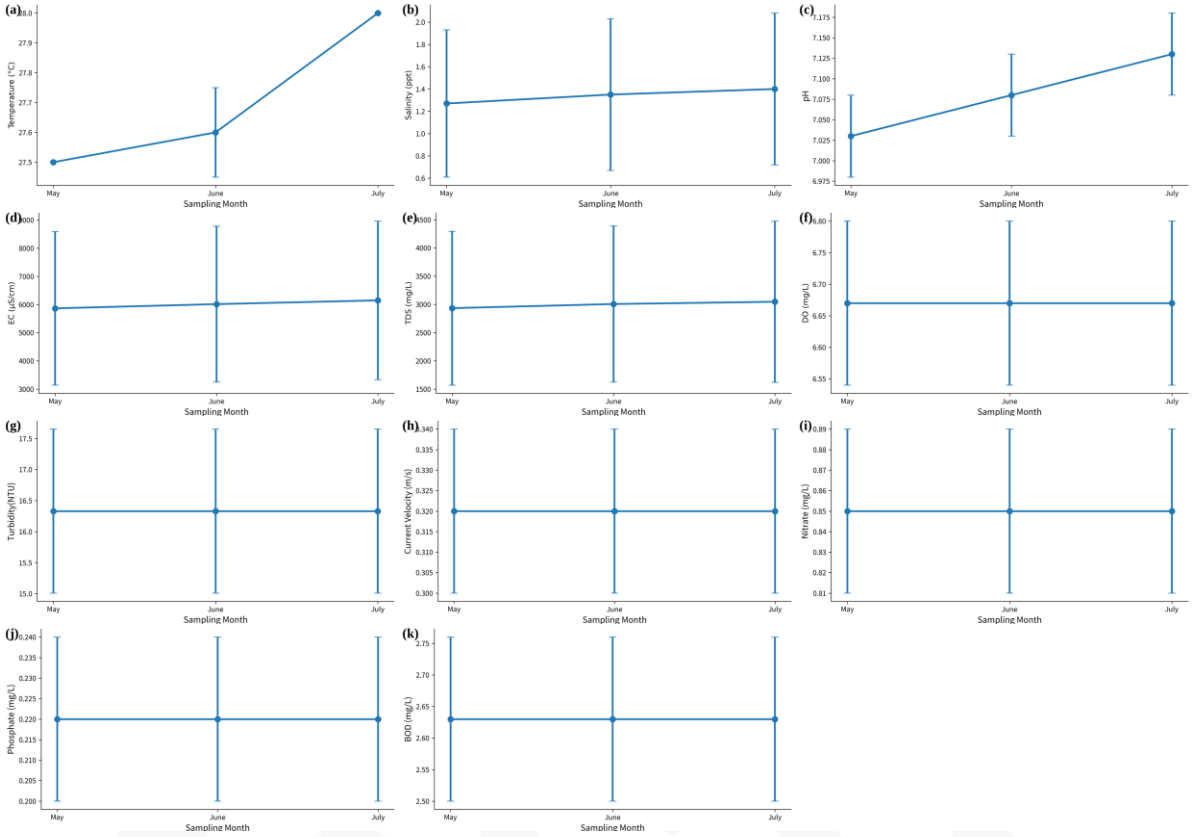


Fig. A1. Monthly variation (mean ± SD across stations) in (a) temperature, (b) salinity, (c) pH, (d) electrical conductivity, (e) total dissolved solids, (f) dissolved oxygen, (g) turbidity, (h) current velocity, (i) nitrate, (j) phosphate and (k) BOD_5 in the Egbelu reach of the New Calabar River, May–July 2026.