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Spatial and Seasonal Variation in Physicochemical Characteristics and Zooplankton Composition Across Upper Lagoon, Industrial and Marine Ecological Zones of the Lagos Ship Channel, Nigeria

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ABSTRACT: The Lagos Ship Channel is a major coastal waterway that links Lagos Lagoon with the Atlantic Ocean and supports diverse ecological processes, fisheries, and maritime activities. However, information on how environmental gradients influence zooplankton community structure within the channel remains limited. Hence, the objective of this paper was to investigate the spatial and seasonal variation in physicochemical characteristics and zooplankton communities across three ecological zones (Upper Lagoon, Industrial and Marine) of the Lagos Ship Channel, Nigeria using appropriate standard methods. Significant spatial differences were observed in salinity, pH and nitrate concentrations ($p < 0.05$), demonstrating a pronounced environmental gradient from the Upper Lagoon to the Marine Zone. A total of 19 zooplankton taxa were recorded, with larval forms and cyclopoid copepods dominating the assemblage. The Industrial Zone supported the highest zooplankton abundance (1175 individuals), whereas the Marine Zone exhibited the greatest species richness (16 taxa) and Shannon diversity ($H' = 1.799$). Although total abundance did not differ significantly between seasons ($p > 0.05$), species richness and diversity were significantly higher during the wet season ($p < 0.05$). The findings demonstrate that environmental gradients strongly structure zooplankton community composition within the Lagos Ship Channel and highlight the ecological importance of the channel as both a productive nursery habitat and a reservoir of aquatic biodiversity. These results provide valuable baseline information for biodiversity conservation, fisheries management and long-term ecological monitoring of Nigeria's coastal ecosystems.

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Coastal lagoons and estuaries are among the world's most productive aquatic ecosystems because they facilitate the exchange of water, nutrients and organisms between freshwater and marine environments, thereby supporting high biological productivity, fisheries and biodiversity (Abdul *et al.*, 2016). Increasing urbanisation, industrialisation, dredging and maritime activities have altered the

ecological integrity of many tropical coastal ecosystems through changes in water quality, nutrient dynamics and habitat conditions, with consequent effects on plankton communities (Elegbeleye and Onyema, 2019; Omorogbe *et al.*, 2024). Zooplankton occupy a central position in aquatic food webs by transferring energy from primary producers to higher trophic levels and are widely recognised as sensitive

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indicators of environmental change because of their rapid response to variations in physicochemical conditions (Emmanuel and Onyema, 2007; Egborge, 1994). Studies in Nigerian coastal waters have similarly demonstrated that environmental gradients strongly influence zooplankton abundance, diversity and community composition (Okogwu and Ugwumba, 2006; Oronsaye, 2006). The Lagos coastal ecosystem comprises an interconnected network of lagoons, creeks, estuaries and coastal waters that support fisheries, transportation and other socio-economic activities. The Lagos Ship Channel forms the principal navigational corridor linking Lagos Lagoon with the Atlantic Ocean and is subjected to intense shipping, industrial operations, dredging and urban runoff. These activities have the potential to modify environmental conditions and consequently influence plankton communities (Agarin *et al.*, 2019).

Although plankton communities have been investigated in Lagos Lagoon, Ologe Lagoon and adjacent coastal waters (Okogwu and Ugwumba, 2006; Balogun and Ajani, 2021; Akanmu and Onyema, 2020), comparatively little information is available for the Lagos Ship Channel itself, despite its importance as the principal navigational corridor linking Lagos Harbour with the Atlantic Ocean. Information on zooplankton community structure within this shipping corridor is therefore essential for understanding ecosystem functioning, biodiversity conservation and sustainable fisheries management. Hence, the objective of this paper was to investigate the spatial and seasonal variation in physicochemical characteristics and zooplankton communities across three ecological zones (Upper Lagoon, Industrial and Marine) of the Lagos Ship Channel, Nigeria.

MATERIALS AND METHODS

Description of the study area: The study was conducted along the Lagos Ship Channel, a major navigational corridor connecting Lagos Harbour with the Atlantic Ocean in south-western Nigeria. The channel receives freshwater inflow from Lagos Lagoon while maintaining direct connectivity with marine waters, creating pronounced physicochemical gradients along the lagoon–marine continuum.

Sample collection and treatment: Monthly sampling was conducted from November 2021 to October 2022, encompassing both the dry and wet seasons. Eleven sampling stations were established along the channel and grouped into three ecological zones according to their hydrological characteristics and proximity to marine influence. Sampling stations were subsequently grouped into the three ecological

zones to evaluate spatial variation in environmental characteristics and zooplankton communities. The Upper Lagoon Zone comprised Berger Bridge (BB) and Ibafon (IB), the Industrial Zone comprised Ajegunle Mouth (AJM), Ajegunle Inside (AJI), Folawiyi Tank Farm (YF), Sea School (SS) and Inagbe (IN), while the Marine Zone comprised Federal Palace (FP), NIOMR Jetty (NJ), Takwa Bay (TB) and Sea Mouth (SH) (Figure 1).

Sample analysis methodologies: Surface water samples and zooplankton were collected simultaneously during each sampling exercise. Water temperature, pH, salinity and dissolved oxygen were measured *in situ* using calibrated portable field meters according to the manufacturers' instructions. Additional water samples were collected in clean polyethylene bottles and transported to the laboratory for the determination of nitrate, phosphate and total suspended solids (TSS) following standard procedures of the American Public Health Association (APHA, 2017). Zooplankton samples were collected using a 55 µm mesh plankton net towed horizontally for approximately five minutes at each sampling station. The collected samples were immediately preserved in 4% buffered formalin and transported to the laboratory for identification and enumeration. Zooplankton organisms were sorted and identified under compound and inverted microscopes to the lowest practicable taxonomic level using the taxonomic keys of Jeje and Fernando (1986) and Newell *et al.* (2004). Taxonomic nomenclature was verified using the World Register of Marine Species (WoRMS) and the Barcode of Life Data System (BOLD).

Statistical Data Analysis: Descriptive statistics were computed for all physicochemical variables. One-way analysis of variance (ANOVA) was used to test for differences in physicochemical parameters among ecological zones, followed by Tukey–Kramer Honestly Significant Difference (HSD) tests where significant differences occurred. Zooplankton community structure was evaluated using total abundance, species richness and the Shannon–Wiener diversity index (H'). Because these biological variables did not satisfy the assumptions of normality, spatial differences were assessed using the Kruskal–Wallis test, while seasonal differences between the dry and wet seasons were evaluated using the Mann–Whitney U test. All statistical analyses were performed using JMP® Pro Version 19 (SAS Institute Inc., Cary, NC, USA), and statistical significance was accepted at $p < 0.05$.

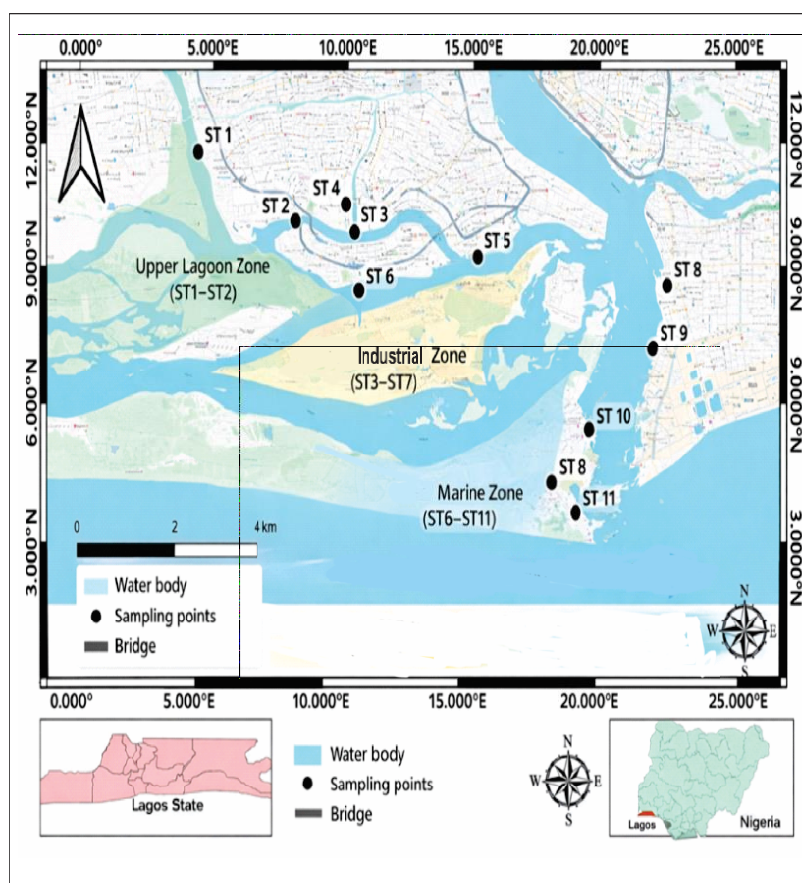


Fig 1: Map of the study area showing sampling stations

RESULTS AND DISCUSSION

Physicochemical characteristics: Physicochemical parameters differed significantly among the three ecological zones of the Lagos Ship Channel. Salinity showed the greatest spatial variation ($F = 14.24$, $P < 0.0001$), increasing significantly from the Upper Lagoon (12.28 ± 1.64 ppt) and Industrial Zone (11.40 ± 1.16 ppt) to the Marine Zone (19.16 ± 1.04 ppt) (Table 1; Figure 2). Similarly, pH differed significantly ($F = 7.88$, $P = 0.0006$), with the Marine Zone recording the highest value, while water temperature was significantly higher in the Industrial Zone than in the Marine Zone ($F = 3.82$, $P = 0.0172$)

(Table 1; Figure 3). Nitrate concentrations declined significantly from the Upper Lagoon to the Marine Zone ($F = 5.96$, $P = 0.0034$), whereas dissolved oxygen, total suspended solids and phosphate showed no significant spatial variation ($P > 0.05$) (Table 1; Figure 4). These patterns demonstrate a pronounced lagoon–marine environmental gradient, with increasing marine influence towards the Atlantic Ocean. Similar relationships between salinity, nutrient availability and plankton distribution have been reported for Nigerian coastal ecosystems (Abdul et al., 2016; Akanmu and Onyema, 2020; Omorogbe et al., 2024).

Table 1: mean ($\pm$ SD) physicochemical characteristics across ecological zones of the Lagos ship channel, Nigeria.

Parameter	Upper Lagoon zone	Industrial zone	Marine zone	F-value	p-value
Water Temperature ($^{\circ}\text{C}$)	$28.63 \pm 0.40^{\text{ab}}$	$29.38 \pm 0.28^{\text{a}}$	$28.33 \pm 0.25^{\text{b}}$	3.82	0.0172*
pH	$7.05 \pm 0.05^{\text{b}}$	$7.27 \pm 0.08^{\text{ab}}$	$7.45 \pm 0.05^{\text{a}}$	7.88	0.0006*
Salinity (ppt)	$12.28 \pm 1.64^{\text{b}}$	$11.40 \pm 1.16^{\text{b}}$	$19.16 \pm 1.04^{\text{a}}$	14.24	<0.0001*
Dissolved Oxygen (mg L^{-1})	$3.61 \pm 0.16^{\text{a}}$	$3.73 \pm 0.15^{\text{a}}$	$3.83 \pm 0.14^{\text{a}}$	0.43	0.634
Total Suspended Solids (mg L^{-1})	$16.08 \pm 2.04^{\text{a}}$	$17.04 \pm 2.54^{\text{a}}$	$11.37 \pm 1.92^{\text{a}}$	2.05	0.1330
Nitrate (mg L^{-1})	$12.42 \pm 3.51^{\text{a}}$	$8.74 \pm 1.44^{\text{ab}}$	$4.53 \pm 1.29^{\text{b}}$	5.96	0.0034*
Phosphate (mg L^{-1})	$1.16 \pm 0.22^{\text{ab}}$	$1.55 \pm 0.41^{\text{a}}$	$0.64 \pm 0.16^{\text{b}}$	2.91	0.0581

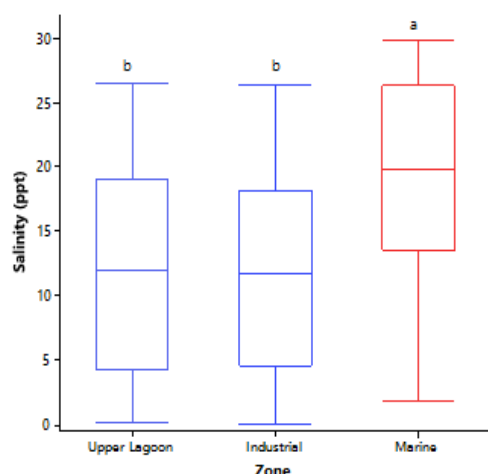


Fig 2: Boxplots showing salinity variation across ecological zones of the Lagos ship channel. different letters indicate significant differences among zones.

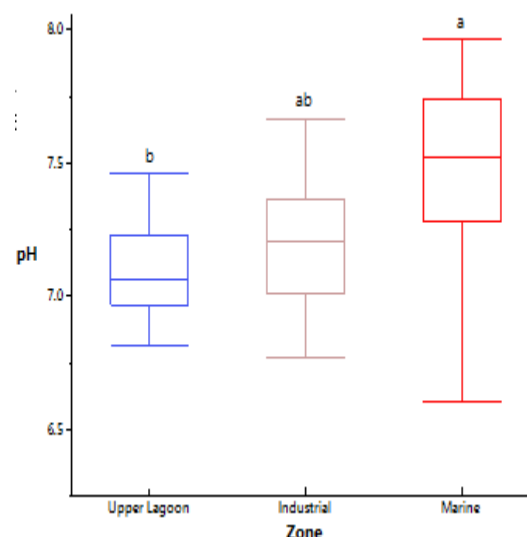


Fig 4: Boxplots showing nitrate variation across ecological zones of the Lagos ship channel. different letters indicate significant differences among zones

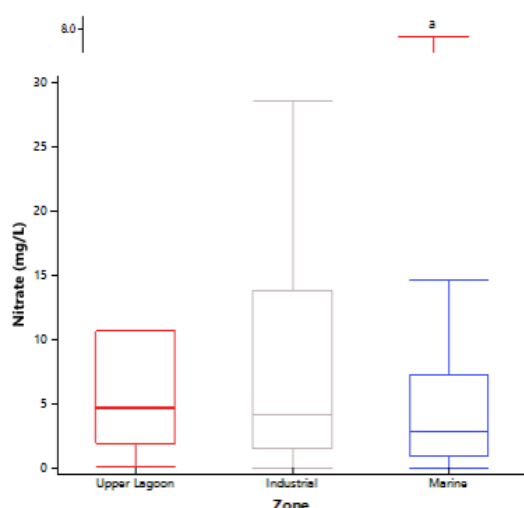


Fig 3: Boxplots showing pH variation across ecological zones of the Lagos ship channel. different letters indicate significant differences among zones

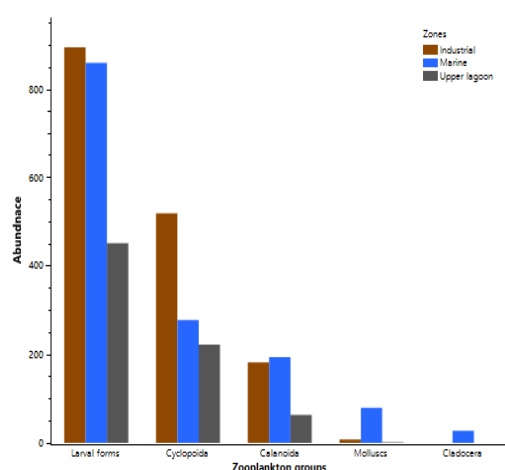


Fig 5: Relative abundance of major zooplankton groups across ecological zones of the Lagos ship channel.

Zooplankton composition and community structure: Nineteen zooplankton taxa representing copepods, cladocerans, chaetognaths, rotifers, molluscs and larval forms were recorded (Table 2). Larval forms dominated the assemblage throughout the study area, particularly in the Industrial (896 individuals) and Marine (863 individuals) zones. Cyclopoid copepods, especially *Oithona brevicornis*, *Oithona nana* and *Cyclopina longicornis*, were most abundant in the Industrial zone, whereas marine-associated taxa including *Acartia tonsa*, *Penilia avirostris*, *Microsetella norvegica*, *Pseudocalanus elongatus* and *Lucifer hanseni* occurred predominantly in the Marine zone (Figure 5). Although larval forms dominated the zooplankton assemblage in all ecological zones, marked differences were observed in the abundance of the major taxonomic groups and the overall community structure. The predominance of larval forms indicates that the Lagos Ship Channel functions as an important nursery habitat for estuarine and marine organisms, a pattern similarly reported in Ologe Lagoon and Lagos tidal creeks (Okogwu and Ugwumba, 2006; Emmanuel and Onyema, 2007). Additionally, this indicates that the Lagos Ship Channel functions as a heterogeneous ecosystem where physicochemical conditions influence the composition and distribution of zooplankton communities. The observed progressive replacement of lagoonal taxa by marine species reflects increasing salinity and marine connectivity along the channel, consistent with previous observations in Nigerian estuarine ecosystems (Okogwu and Ugwumba, 2006; Omorogbe et al., 2024).

Table 2: Distribution and abundance of zooplankton taxa across ecological zones of the Lagos ship channel.

Taxon	Upper Lagoon	Industrial Zone	Marine Zone	Total
Copepod larvae	273	665	600	1,538
<i>Oithona brevicornis</i>	73	254	158	485
<i>Oithona nana</i>	81	93	81	255
Barnacle larvae	60	43	53	156
Fish eggs	40	7	60	107
<i>Paracalanus parvus</i>	20	33	19	72
<i>Cyclopina longicornis</i>	19	52	0	71
Bivalve larvae	31	1	36	68
<i>Euterpina acutifrons</i>	3	3	50	56
Bivalve	2	8	37	47
Mollusc larvae	0	0	19	19
<i>Acartia tonsa</i>	0	1	16	17
<i>Penilia avirostris</i>	0	0	14	14
<i>Paracalanus aculeatus</i>	0	9	3	12
<i>Microsetella norvegica</i>	0	0	12	12
<i>Pseudocalanus elongatus</i>	0	0	8	8
<i>Sagitta bicumpata</i>	2	5	0	7
<i>Lucifer hansenii</i>	0	0	3	3
Keratella	0	1	0	1

Table 3: Zooplankton community structure across ecological zones of the Lagos ship channel.

Variable	Upper Lagoon zone	Industrial zone	Marine Zone	H Statistic	p-value
Total Abundance	604	1175	1169	6.63	0.036
Species Richness	11	14	16	9.95	0.007
Shannon Diversity (H')	1.731	1.372	1.799	6.16	0.046

Community structure also varied significantly among ecological zones (Table 3). Total abundance differed significantly ($H = 6.63$, $P = 0.036$), with the Industrial Zone recording the highest abundance (1,175 individuals), while species richness ($H = 9.95$, $P = 0.007$) and Shannon diversity ($H = 6.16$, $P = 0.046$) were highest in the Marine Zone. Although the Industrial Zone supported greater numerical abundance, the Marine Zone contained a more taxonomically diverse assemblage, indicating that higher abundance did not necessarily correspond with greater biodiversity. However increased marine influence appears to promote species replacement and community complexity within the seaward section of the channel. This greater diversity observed in the Marine Zone is attributable to stronger marine connectivity and increased habitat heterogeneity, which promote species replacement and coexistence in transitional coastal ecosystems (Abdul *et al.*, 2016; Akanmu and Onyema, 2020). Seasonal variation influenced diversity more strongly than abundance (Table 4). Total zooplankton

abundance did not differ significantly between the dry and wet seasons ($P = 0.832$), whereas species richness ($U = 1660.5$, $P = 0.016$) and Shannon diversity ($U = 1598.0$, $P = 0.008$) were significantly higher during the wet season. The relatively stable abundance observed throughout the study period may indicate that the Lagos Ship Channel provides favourable environmental conditions capable of supporting continuous zooplankton production irrespective of season.

However, increased richness and diversity during the wet season suggest that rainfall, freshwater inflow and increased hydrological connectivity may facilitate the introduction and coexistence of additional zooplankton species. Therefore, seasonal increases in diversity during the wet season may reflect enhanced freshwater inflow, nutrient enrichment and recruitment of planktonic organisms, consistent with observations from other Nigerian coastal waters (Balogun and Ajani, 2021; Omorogbe *et al.*, 2024).

Table 4: Seasonal variation in abundance, richness and diversity of zooplankton communities in the Lagos ship channel.

Variable	Wet Season (Mean $\pm$ SD)	Dry Season (Mean $\pm$ SD)	Test Statistic (U)	p-value
Total Abundance	1,467	1,481	2225.0	0.832
Species Richness	2.89 $\pm$ 1.57	2.29 $\pm$ 1.35	1660.5	0.016
Shannon Diversity (H')	0.745 $\pm$ 0.476	0.533 $\pm$ 0.464	1598.0	0.008

Conclusion: This study investigated the spatial and seasonal variation in physicochemical characteristics

and zooplankton assemblages across the Lagos Ship Channel to improve understanding of ecological

processes within this important lagoon–marine ecosystem. The findings establish that environmental gradients, particularly salinity, play a major role in structuring zooplankton communities and demonstrate the ecological significance of the channel as a productive nursery habitat and biodiversity reservoir. These observations provide valuable baseline information for ecological monitoring, conservation planning and sustainable fisheries management in the Lagos coastal ecosystem. Although the study was based on a one-year sampling programme, it provides a robust benchmark for future assessments. Further investigations integrating long-term monitoring, molecular techniques and broader environmental stressors are recommended to improve understanding of ecosystem responses to increasing anthropogenic and climate-related pressures.

DECLARATIONS

Ethical Approval: This study did not involve human participants or animal experimentation and therefore did not require formal ethical approval. All procedures involving data handling and analysis were conducted responsibly and in accordance with standard academic and institutional guidelines.

Disclaimer on Artificial Intelligence usage: Author(s) hereby declare that no generative Artificial Intelligence (AI) technologies such as Large Language Models (ChatGPT, COPILOT, XLNet, Ernie 3.0 Titan etc) and text-to-image generators have been used during writing or editing of this manuscript.

Declaration of Conflict of Interest: The authors declare that there is no known conflict of interest or personal relationship that could have influenced the work reported in this paper.

Declaration of Data Availability: The data used in this study are available from the first author upon reasonable request.

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