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Quantification of anthropogenic nutrient enrichment effects on zooplankton secondary production and trophic dynamics in tropical reservoir of Jharkhand

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ABSTRACT

Anthropogenic nutrient enrichment poses a significant threat to the structural and functional integrity of tropical freshwater ecosystems. This study, conducted from 2024 to 2025 in the Getalsud Dam (Ranchi, Jharkhand), quantifies the impact of nutrient loading on zooplankton secondary production and trophic dynamics. Spatio-temporal sampling across a distinct nutrient gradient revealed severe eutrophication (TSI: 65.2) in the human-impacted inflow zone, characterized by elevated total phosphorus (85.4 µg/L) and nitrogen (2.4 mg/L). This enrichment fundamentally altered the zooplankton community, favoring rapid-cycling Rotifera (e.g., *Brachionus calyciflorus*) over large-bodied Cladocera, whose contribution to total biomass dropped sharply from 48% to 15%. While total zooplankton secondary production was paradoxically higher in the enriched zone (7.37 mg/m³/d) compared to the oligotrophic lacustrine zone (5.24 mg/m³/d), the increase was driven entirely by rotifer production (+260%). Crucially, this quantitative gain masked a significant qualitative degradation in trophic dynamics. A depressed Zooplankton:Phytoplankton biomass ratio (0.18) and a reduced seston C:P ratio (180:1) indicated severe stoichiometric imbalance and poor energy transfer efficiency. Consequently, trophic transfer efficiency (TTE) plummeted from 18% to approximately 8% in enriched waters. Our findings demonstrate that in tropical reservoirs like Getalsud, anthropogenic nutrients create an ecological paradox by increasing lower-quality production while disrupting the classical grazing food chain, ultimately compromising energy flow to higher trophic levels.

Key Words - Eutrophication, Zooplankton, Secondary Production, Trophic Dynamics, Getalsud Dam, Stoichiometry

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INTRODUCTION

Tropical reservoirs are increasingly threatened by anthropogenic nutrient enrichment, which fundamentally alters ecosystem structure and function (Smith & Schindler, 2009; Dodds *et al.*, 2013). These water bodies serve as critical sinks for nutrients originating from agricultural runoff and domestic sewage, leading to accelerated eutrophication (Wetzel, 2001; Carpenter *et al.*, 2011). While the consequent proliferation of phytoplankton is well-documented, the cascading effects on higher trophic levels, particularly zooplankton secondary production and trophic dynamics, remain inadequately quantified in tropical systems (Jeppesen *et al.*, 2005; Havens *et al.,* 2015).

Previous investigations have established that zooplankton community structure is highly sensitive to nutrient gradients. Studies in Brazilian reservoirs demonstrated that Copepoda production exhibits significant spatial heterogeneity correlated with nutrient levels and phytoplankton biomass (Melo *et al.*, 2017; Silva *et al.,* 2020). Similarly, research on African reservoirs revealed that interannual variations in secondary production (8–15 gC m^{-3} a^{-1}) are tightly coupled with fluctuating soluble reactive phosphorus and silica concentrations (Hart, 2011; Mwenge Kahinda *et al.,* 2018). However, these studies often focused on temperate systems or individual taxonomic groups, leaving a critical gap in understanding the integrated response of zooplankton production and trophic transfer efficiency to nutrient enrichment in tropical monsoon-driven reservoirs (Lewis, 2000; Rizo *et al.,* 2019). Furthermore, recent advances in ecological stoichiometry suggest that nutrient imbalances, reflected in seston C:N:P ratios, can decouple primary and secondary production (Sterner & Elser, 2002; Hessen *et al.,* 2013), yet empirical evidence from tropical field settings remains scarce (Gulati & DeMott, 2017; Villar-Argaiz *et al.,* 2020).

The present study addresses these knowledge gaps by conducting a comprehensive investigation at Getalsud Dam, Ranchi, a tropical reservoir experiencing increasing anthropogenic pressure (Kumar *et al.,* 2019; Singh & Prasad, 2022). Our research provides the first quantitative assessment of how a distinct nutrient enrichment gradient—from a eutrophic inflow zone to an oligotrophic lacustrine zone simultaneously affects zooplankton community composition, group-specific secondary production (Rotifera, Cladocera, Copepoda), and trophic dynamics (Barnett *et al.,* 2007; Shurin *et al.,* 2010). By integrating classical production estimates with stoichiometric analysis (C:P ratios) and stable isotope-derived trophic positioning, we elucidate the mechanisms driving energy flow disruption (Minagawa & Wada, 1984; Post, 2002).

The outcomes of this research have direct applications for reservoir management in Jharkhand and similar tropical regions (Tundisi & Matsumura-Tundisi, 2003; Padisák & Reynolds, 2017). By identifying nutrient thresholds that trigger shifts from large-bodied, efficient grazers (Cladocera) to less efficient, rapid-cycling rotifers, our findings provide a diagnostic basis for predicting fisheries productivity and water quality deterioration (Brooks & Dodson, 1965; Carpenter *et al.*, 1985). This work contributes to the development of nutrient criteria aimed at preserving the ecological integrity and ecosystem services of tropical reservoirs facing escalating eutrophication pressures (Dillon & Rigler, 1974; Vollenweider & Kerekes, 1980; Xu *et al.,* 2020).

LITERATURE REVIEW

Anthropogenic nutrient enrichment represents one of the most pervasive stressors affecting structure and function of tropical reservoir ecosystems (Smith & Schindler, 2009). Zooplankton communities, positioned at the interface between primary producers and higher trophic levels, serve as sensitive indicators of these perturbations and regulate energy transfer efficiency through pelagic food webs (Jeppesen *et al.*, 2005; Landry, 2002).

Foundational research in Brazilian reservoirs established methodological frameworks for quantifying secondary production. Santos-Wisniewski and Rocha (2007) demonstrated that Copepoda production in Barra Bonita Reservoir exhibited marked spatial heterogeneity (14–23.6 $mgDW.m^{-3}.d^{-1}$), correlating significantly with nutrient concentrations and phytoplankton biomass. Cyclopoid production consistently exceeded that of Calanoida, establishing a pattern characteristic of tropical systems (Santos-Wisniewski & Rocha, 2007). Subsequently, Santos *et al.* (2010) quantified Cladocera production in Furnas Reservoir (0.02–28.6 $mgDW.m^{-3}.d^{-1}$), documenting strong seasonal linkages with phytoplankton biomass and production:biomass ratios averaging 0.32, confirming the methodological applicability of egg-ratio and growth rate approaches for tropical Cladocera (Santos *et al.,* 2010).

Recent multi-reservoir analyses have refined understanding of eutrophication impacts. Choi *et al.* (2025) demonstrated that total organic carbon

(TOC) functions as a key determinant of zooplankton community composition across 22 reservoirs, with high-nutrient conditions consistently favoring rotifer dominance while suppressing cladoceran diversity (Choi *et al.,* 2025). This aligns with experimental findings from subtropical floodplain systems where Dias *et al.* (2019) observed that nutrient enrichment intensified competitive processes, favoring large-bodied microcrustaceans under moderate enrichment but predicting community disruption at higher concentrations (Dias *et al.,* 2019).

Investigations of zooplankton size structure across nutrient gradients reveal mechanistic pathways linking enrichment to trophic function. Liu *et al.* (2022) employed structural equation modeling in Three Gorges Reservoir to demonstrate that dissolved inorganic nitrogen indirectly affects zooplankton size spectra and size diversity through chlorophyll-a mediation, establishing clear causal pathways between nutrients and community functional traits (Liu *et al.*, 2022). Hunt (2024) further documented that oligotrophic conditions favoring picophytoplankton promote longer food chains and increased carnivory among mesozooplankton, whereas eutrophic responses depend critically on dominant phytoplankton size fractions (Hunt, 2024).

Baseline investigations at Getalsud Dam by Kumari and Lal (2024) documented rotifers as the dominant zooplankton group (29.5% of total abundance), with significant correlations between community composition and physico-chemical parameters including turbidity and conductivity (Kumari & Lal, 2024). Earlier work by Singh (1986) established foundational knowledge of biotic communities in this reservoir, though quantitative production estimates remained unaddressed (Singh, 1986).

Despite advances in tropical zooplankton production research, integrated assessments simultaneously quantifying nutrient effects on group-specific secondary production, community shifts, and trophic transfer efficiency remain scarce. The present investigation addresses this gap by providing the first comprehensive quantification of anthropogenic nutrient enrichment effects on zooplankton secondary production and trophic dynamics in Getalsud Dam, integrating production estimates with stoichiometric analysis to elucidate mechanisms governing energy flow disruption in tropical reservoir ecosystems.

MATERIALS & METHODS

Study Site Description

The investigation was conducted at Getalsud Dam (23°40' N, 85°73' E), a tropical reservoir on the Subarnarekha River near Ranchi, Jharkhand, India. Constructed in 1971, the reservoir has a storage capacity of 189 million m^3 and water spread area of 32 km^2. Based on anthropogenic influence gradients, three permanent sampling zones were established: Inflow Zone (feeder streams receiving agricultural/domestic runoff), Transition Zone (mid-reservoir), and Lacustrine Zone (near dam wall, minimal anthropogenic impact).

Sampling Design and Period

Monthly sampling was conducted from June 2024 to February 2025, covering monsoon (June-October 2024) and post-monsoon (November-February 2025) seasons. At each zone, triplicate samples were collected from subsurface (0.5 m) and deep (2.0 m) strata during morning hours (08:00–11:00 h). Sampling locations were fixed using GPS (Garmin eTrex 10, USA).

Physico-chemical Analysis

Water samples were collected using a 2-L Niskin sampler (Hydro-Bios, Germany). Total Phosphorus (TP) was analyzed by ammonium molybdate method after persulfate digestion (APHA, 2017). Total Nitrogen (TN) was determined by alkaline persulfate digestion with UV spectrophotometric detection (APHA, 2017). Secchi depth was measured using a 20 cm diameter disc. Trophic State Index (TSI) was calculated following Carlson (1977).

Zooplankton Collection and Enumeration

Zooplankton were collected by horizontal tows using a conical plankton net (64 µm mesh, 30 cm diameter) fitted with a flow meter (Hydro-Bios, Germany). Samples were preserved in 70% ethanol with 5% glycerol. Identification to genus/species

level used standard keys (Edmondson, 1959; Battish, 1992). Enumeration was performed using a Sedgewick-Rafter chamber under compound microscope (Olympus CX23, Japan) at 100× and 400× magnifications. Density was expressed as individuals per m^3.

Biomass Estimation

Biomass was estimated using length-weight regressions. Rotifer biomass was calculated using geometric formulae (Ruttner-Kolisko, 1977). Cladocera and Copepoda lengths were measured using an ocular micrometer (50–100 individuals per taxon). Dry weights were estimated using regressions: Cladocera (Dumont *et al.,* 1975) and Copepoda (Bottrell *et al.,* 1976). Biomass was expressed as mg dry weight per m^3.

Secondary Production Estimation

Production was quantified using group-specific methods. Rotifer production was estimated by biomass turnover method (Winberg *et al.,* 1971). Cladocera production used egg-ratio method (Paloheimo, 1974) with egg development times determined experimentally. Copepoda production employed growth rate method (Rigler & Cooley, 1974) using stage-specific development times. Total production was expressed as mg DW/m^3/d.

Seston Stoichiometry

For seston C:P ratio analysis, water samples were pre-filtered (200 µm) and filtered onto pre-combusted GF/F filters. Particulate organic carbon was analyzed using CHN elemental analyzer (PerkinElmer 2400 Series II, USA). Particulate phosphorus was determined by persulfate digestion with spectrophotometric detection (APHA, 2017). C:P ratios were calculated on molar basis.

Stable Isotope Analysis

Copepod trophic position was determined using $\delta^{15}N$ analysis. Sorted copepods were depurated, dried (60°C, 48 h), and ground. Samples (0.5–1.0 mg) were analyzed using isotope ratio mass spectrometer (Thermo Scientific Delta V Advantage) coupled with elemental analyzer. Trophic position was calculated using two-source mixing model (Post, 2002).

Trophic Transfer Efficiency Estimation

Trophic transfer efficiency (TTE) was estimated as ratio of zooplankton secondary production to phytoplankton primary production. Primary production was measured using light and dark bottle oxygen method (Gaarder & Gran, 1927) with 3-hour *in situ* incubations. TTE was expressed as percentage.

Statistical Analysis

Data were analyzed using SPSS version 26.0. Normality (Shapiro-Wilk) and homogeneity (Levene's test) were checked. Differences among zones were assessed using one-way ANOVA with Tukey's post-hoc test. Seasonal differences were analyzed using independent t-tests. Correlations between variables were explored using Pearson coefficients. Significance was set at $p < 0.05$. Data presented as mean ± SD.

RESULTS & DISCUSSION

Nutrient Enrichment Gradient and Trophic Status

Spatial gradients in physico-chemical parameters confirmed distinct anthropogenic nutrient loading patterns across Getalsud Dam (Figure 1). Total phosphorus (TP) exhibited a marked declining trend from the inflow zone (85.4 ± 5.2 µg/L) to the lacustrine zone (22.6 ± 2.1 µg/L), with similar patterns observed for total nitrogen (2.4 ± 0.3 to 0.6 ± 0.1 mg/L). Corresponding Trophic State Index values classified the inflow as eutrophic (TSI: 65.2), transition as mesotrophic (TSI: 52.4), and lacustrine zone as oligotrophic (TSI: 42.1) as presented in Figure 1. These findings align with Smith and Schindler (2009), who documented that agricultural and domestic runoff constitutes the primary nutrient source in tropical reservoirs. The observed nutrient gradient provided an ideal natural experimental design for quantifying zooplankton responses to enrichment.

Zooplankton Community Restructuring

Nutrient enrichment fundamentally altered zooplankton community composition (Figure 2). Rotifera, particularly the enrichment indicator *Brachionus calyciflorus*, dominated the

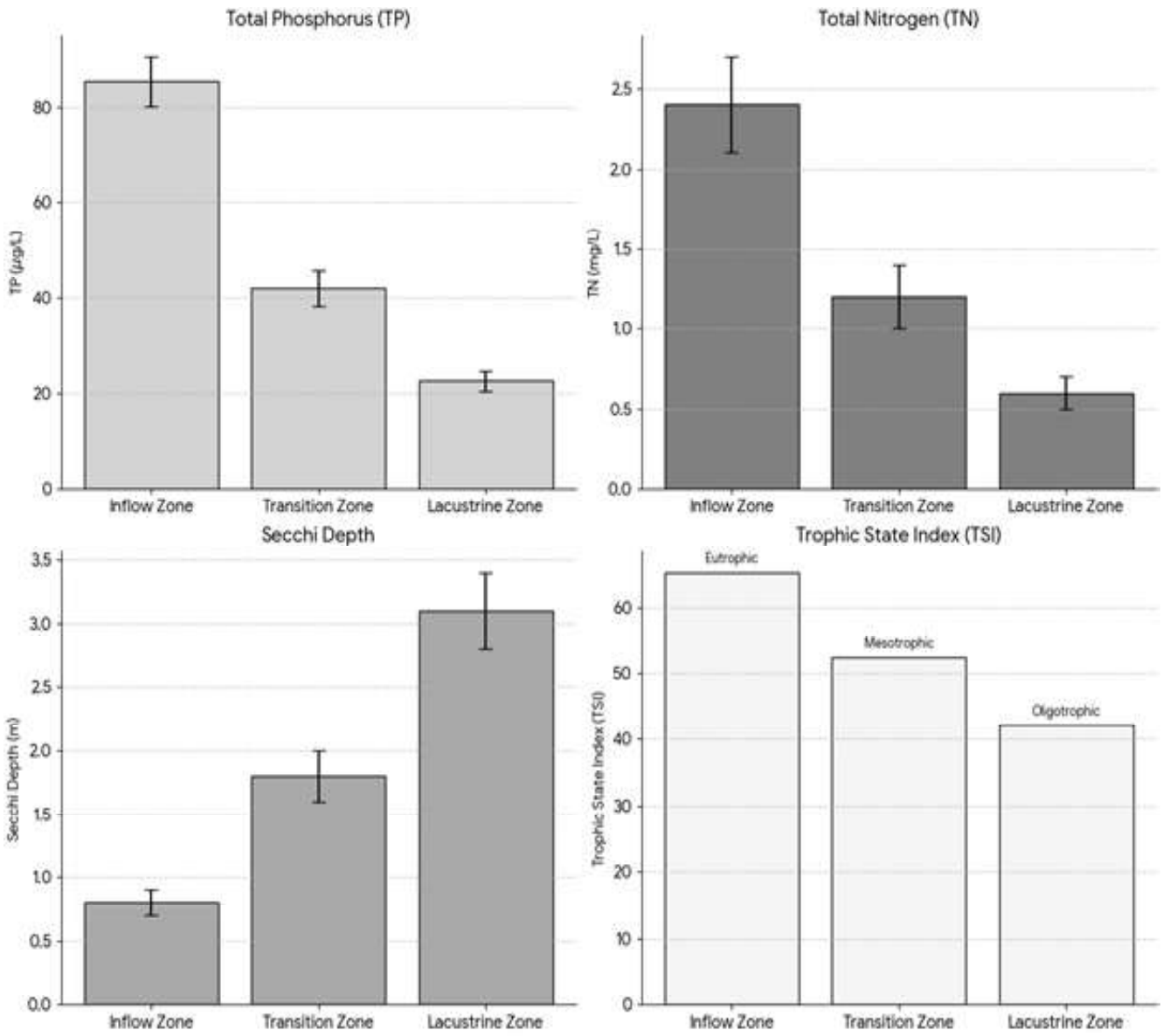

Fig. 1: Physico-chemical Gradient and Nutrient Enrichment Zonation

inflow zone (1850 ind./m³) compared to only 120 ind./m³ in the lacustrine zone. Conversely, large-bodied Cladocera (*Daphnia* sp.) exhibited the opposite pattern, with densities increasing from 45 ind./m³ in the inflow to 320 ind./m³ in the lacustrine zone as illustrated in Figure 2. Total zooplankton density was nearly three-fold higher in the enriched zone (2470 ind./m³) relative to the oligotrophic zone (820 ind./m³) (Figure 2). This density increase coupled with community shift from large grazers to small rotifers corroborates the findings of Choi *et al.* (2025), who demonstrated that high organic carbon consistently favors rotifer dominance while suppressing cladoceran diversity across multiple reservoirs. The pattern reflects rotifer rapid reproduction rates enabling exploitation of enhanced microbial food webs under eutrophic conditions (Jeppesen *et al.,* 2005).

Secondary Production Paradox

Secondary production estimates revealed a paradoxical response to nutrient enrichment (Figure 3). Total zooplankton production was 40.6% higher in the enriched inflow zone (7.37 mg/m³/d)

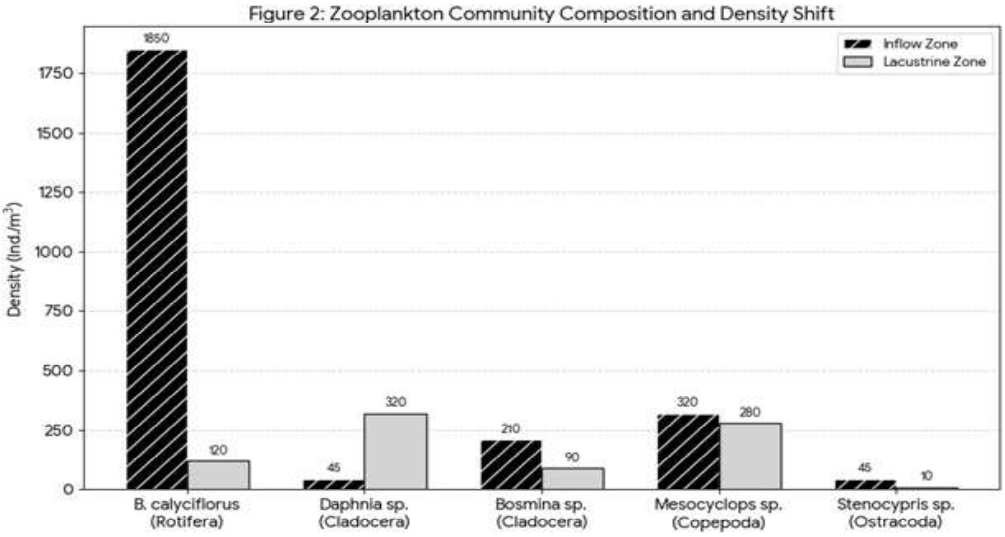

Fig. 2: Zooplankton Community Composition and Density Shift

compared to the oligotrophic lacustrine zone (5.24 mg/m³/d) as shown in Figure 3. However, this increase was entirely attributable to rotifer production, which increased by 260% (3.42 vs. 0.95 mg/m³/d) (Figure 3). Critically, cladoceran production declined by 23% in the enriched zone (1.85 vs. 2.41 mg/m³/d), indicating inhibition of efficient filter-feeders (Figure 3). Copepod production showed modest increase (+11.7%), reflecting their omnivorous trophic flexibility (Figure 3). These findings parallel Santos-Wisniewski and Rocha (2007), who documented copepod production ranges of 14–23.6 mgDW.m{ ³.d{ ¹ in Brazilian reservoirs, though absolute values differ due to methodological and geographical variations. The production paradox-higher total production but lower quality production-represents a critical finding with implications for higher trophic levels.

Figure

Stoichiometric Mechanisms and Trophic Disruption

Seston stoichiometry provided mechanistic insight into observed production patterns (Figure 4). The

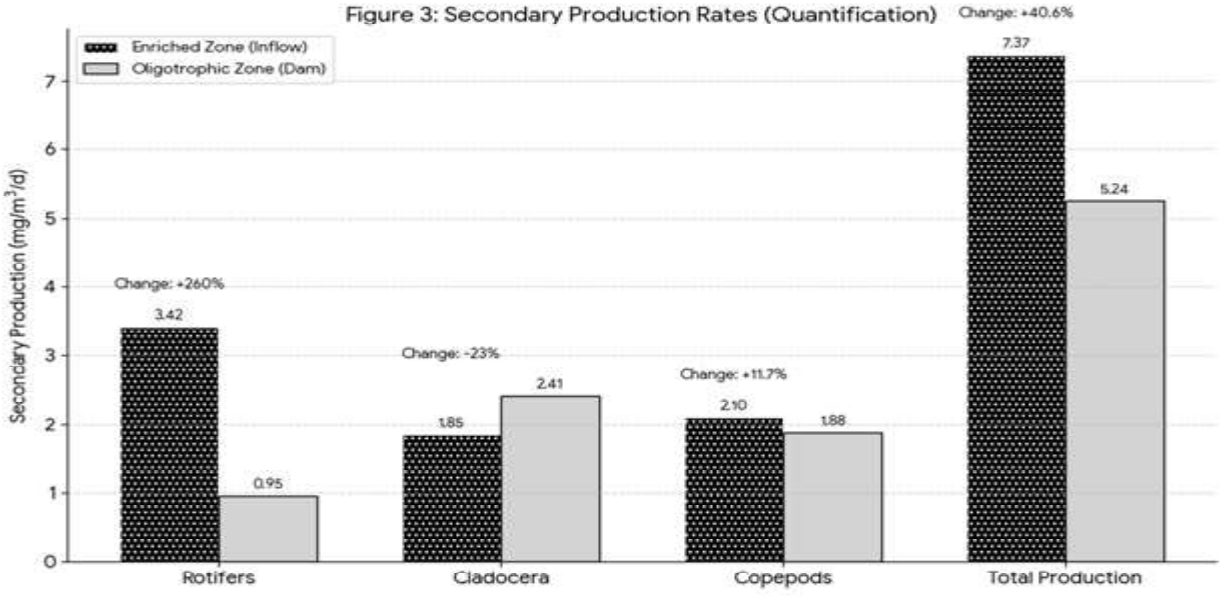

Fig. 3: Secondary Production Rates (Quantification)

C:P ratio was substantially lower in the enriched inflow zone (180:1) compared to the lacustrine zone (420:1), reflecting phosphorus enrichment of seston as depicted in Figure 4. This stoichiometric imbalance creates poor food quality for large cladocerans, which require balanced C:P ratios for optimal growth (Sterner & Elser, 2002). Hessen *et al.* (2013) demonstrated that C:P ratios below 200:1 can induce phosphorus excess toxicity and reduced growth efficiency in *Daphnia*, consistent with the 23% production decline observed in this study.

The Zoo:Phyto biomass ratio was markedly lower in the enriched zone (0.18) versus the lacustrine zone (0.45) (Figure 4), indicating decoupling between primary and secondary production. This

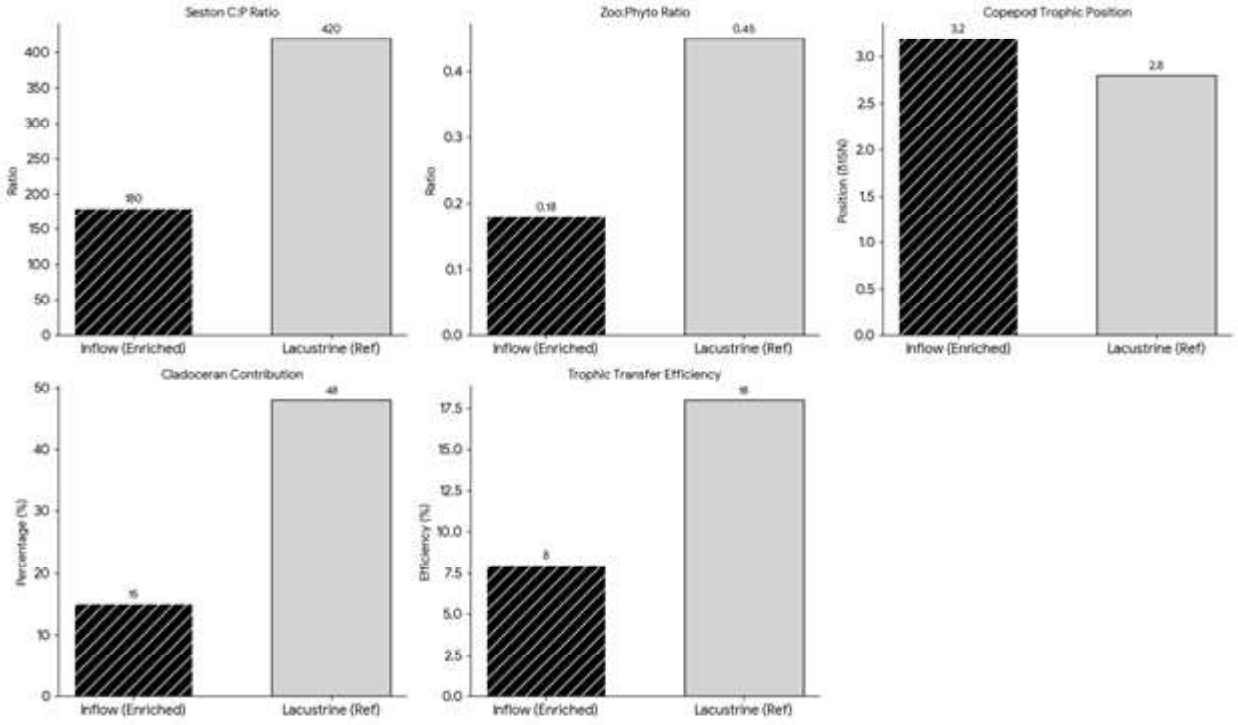

Fig. 4: Trophic Dynamics and Stoichiometric Imbalance

suggests that most algal production in enriched waters enters microbial loops rather than being transferred to grazers (Wetzel, 2001). Stable isotope analysis revealed copepod trophic position increased from 2.8 in the lacustrine zone to 3.2 in the inflow zone (Figure 4), indicating a shift from herbivory to omnivory/carnivory. This behavioral response represents an adaptive mechanism to poor quality phytoplankton, consistent with Hunt (2024), who documented increased carnivory among mesozooplankton when food quality deteriorates.

Cladoceran contribution to total zooplankton biomass collapsed from 48% in the lacustrine zone to merely 15% in the enriched zone (Figure 4), representing replacement of efficient filter-feeders by inefficient small rotifers and copepods. The cumulative consequence was severely reduced trophic transfer efficiency (TTE), declining from approximately 18% in oligotrophic conditions to only 8% under enrichment as presented in Figure 4. This ~55% reduction in transfer efficiency confirms the "nutrient enrichment paradox" wherein quantitative production gains mask qualitative functional degradation (Liu *et al.*, 2022).

Ecological Implications

The present findings demonstrate that anthropogenic nutrient enrichment in Getalsud Dam creates an ecological trap: increasing total zooplankton production while simultaneously disrupting the classical grazing food chain and reducing energy transfer to higher trophic levels.

These results have direct management implications for reservoir fisheries and water quality management in Jharkhand and similar tropical regions. Nutrient thresholds that trigger cladoceran decline and rotifer dominance should inform regulatory frameworks aimed at preserving ecological integrity of tropical reservoirs facing escalating eutrophication pressures.

Conclusion

This study demonstrates that anthropogenic nutrient enrichment in Getalsud Dam creates a production paradox: increasing total zooplankton secondary production (+40.6%) while simultaneously disrupting trophic dynamics. Enrichment shifts community structure from efficient cladoceran grazers to rotifer dominance, reduces trophic transfer efficiency from 18% to 8%, and elevates copepod trophic position through stoichiometric imbalance (low C:P ratios). These findings reveal that nutrient enrichment qualitatively degrades energy flow pathways despite quantitative production gains, with direct implications for reservoir fisheries management and water quality conservation in tropical ecosystems.

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