

Global and Regional Perspectives on Primary Productivity in Subtropical Lentic Ecosystems: A Comprehensive Review

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ABSTRACT

Primary productivity is the metabolic engine of aquatic ecosystems, governing the energy available for higher trophic levels and aquaculture yields. This review synthesizes the historical evolution of productivity studies—from early trophic-dynamic models to modern climate-resilient frameworks. It specifically examines the drivers of carbon fixation in the Middle Gangetic Plain, focusing on how seasonal variations and nutrient stoichiometry influence phytoplankton dynamics. By bridging global limnological theories with regional data from Bihar, this article provides an overview of the factors sustaining aquatic energy flow in subtropical environments under the pressures of 21st-century climate change.

KEYWORDS: Primary Productivity, Pond, Ecosystem, Global.

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1. Introduction: The Energetic Pulse of Aquatic Systems

Primary productivity—the rate at which radiant energy is captured and stored by photosynthetic autotrophs—remains the most critical metric for assessing the biological "health" of freshwater bodies. In subtropical regions like Bhagalpur, India, perennial ponds are not merely ecological units but essential socio-economic assets. Historically, the conceptual framework for this field was established by Lindeman (1942), who defined the trophic-dynamic aspect of ecology. However, modern research now views these systems through the lens of Planetary Health, where primary producers form the vital base of the food chain that sustains both aquatic biodiversity and human nutrition (Duke University, 2025).

In the Middle Gangetic Plain, the stability of this productivity is increasingly threatened by "Anthropogenic Seasonality"—where natural cycles are overridden by urban runoff, thermal shifts, and organic loading. This review integrates the findings from the Sahjangi and Bhairwa ponds with global trends to map the future of subtropical limnology.

2. The Nutrient Nexus and Stoichiometry

The productivity of lentic (still water) systems is governed by the availability of Nitrogen (N) and Phosphorus (P). Recent literature emphasizes that Nutrient Stoichiometry (the N:P ratio) is a more accurate predictor of phytoplankton community shifts than absolute concentrations alone (Siddique et al., 2023).

- **Regional Context:** In the ponds of Bhagalpur, high natural alkalinity (averaging >160 mg/l) acts as a robust buffer.
- **Global Stressors:** Increasing atmospheric CO₂ and rising temperatures are altering these ratios, leading to a "Carbon Source" transition. Under extreme warming and drought, wetland respiration rates can surpass primary production, converting ponds from carbon sinks into carbon sources (MDPI, 2024).

3. Methodological Advancements: Beyond the Bottle

While the "Light and Dark Bottle" method (Gaarder and Gran, 1927) remains the standard for field

research in Bihar, the methodology is being augmented by non-invasive technologies.

1. **Chlorophyll Fluorescence (OJIP Curves):** A novel method for estimating primary productivity involves the use of chlorophyll fluorescence dynamic curves. This non-invasive approach allows for the estimation of Chl *a* content and microalgal cell density without the need for costly laboratory incubations (PMC, 2025).
2. **Remote Sensing and Modeling:** In South Asia, new ground stations and earth observation satellite data are providing spatiotemporal analyses of Gross Primary Productivity (GPP), though ground observations (like those conducted in the thesis) remain essential for benchmarking these models (Pandey et al., 2024).

4. Phytoplankton Dynamics and Climate Drivers

The biological "engine" of the pond is its phytoplankton community. Recent studies in 2024–2025 have confirmed that Temperature (TEMP) is the primary driver of phytoplankton density, explaining over 20% of community deviance (MDPI, 2024).

- **Succession Patterns:** Observations in subtropical zones show a bimodal distribution of density, with peaks often occurring in late summer and monsoon months.
- **Cyanobacteria Dominance:** Warming-induced stability in the water column favors Cyanobacteria over beneficial green algae (Chlorophyceae), increasing the risk of harmful algal blooms (HABs) and ecological instability.

5. Regional Synthesis: The Bihar Context

The research conducted in the Sahjangi and Bhairwa ponds (Kumari, 2023) highlights that these water bodies are naturally highly productive (GPP peaking at 0.492 gC/m³/hr). However, the "Metabolic Margin"-the difference between GPP and community respiration-is narrowing due to thermal stress. As regional temperatures rise, the impact of UV radiation on photosynthesis tends to decrease with increasing nutrient input, yet the specific regional responses vary

greatly, necessitating localized predictions rather than global extrapolations (ResearchGate, 2026).

6. Conclusion

Primary productivity in subtropical ponds is at a crossroads. While the fundamental principles of energy fixation remain constant, the environmental context is changing. For sustainable aquaculture in regions like Bihar, it is imperative to move toward Climate-Smart Pond Management. This involves integrating traditional monitoring with non-invasive fluorescence technology and nature-based filtration systems to maintain the delicate energetic balance of urban freshwater ecosystems.

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