Education

Study of the growth potential and economic viability of *Pangasius pangasius* farming in Uttarakhand using recirculatory aquaculture system

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Abstract

This research study provides a comprehensive analysis of the technical and economic feasibility of deploying Recirculatory Aquaculture Systems (RAS) for the intensive cultivation of the striped catfish (*Pangasianodon hypophthalmus*) within the diverse agro-climatic landscape of Uttarakhand, India. Traditional aquaculture in the Himalayan region has historically been constrained by limited land availability, cold-water temperature fluctuations, and reliance on extensive open-pond practices. This paper evaluates the potential of RAS to mitigate these challenges through high-density production, water recycling, and precise environmental control. Based on simulated growth performance indices and comprehensive economic modeling, the study determines that RAS technology facilitates year-round production of *Pangasius pangasius*, achieving significantly higher survival rates and biomass density compared to conventional systems. Despite the substantial initial capital expenditure required for high-tech infrastructure, the return on investment remains favorable due to market demand, intensive throughput, and optimized resource efficiency. The study concludes that with targeted energy management such as the integration of renewable energy and policy support, RAS-based *Pangasius pangasius* farming offers a highly viable solution for sustainable aquaculture development in Uttarakhand.

Keywords: *Pangasius pangasius*, Recirculatory Aquaculture System (RAS), Economic viability, Uttarakhand aquaculture, Growth performance, Sustainable intensification

Introduction

The global aquaculture sector has witnessed an unprecedented transformation, evolving from traditional, land-extensive pond systems to highly intensive, closed-loop technologies. This evolution is driven by the global imperative to provide high-quality protein to a growing human population while simultaneously minimizing the ecological footprint of food production. In India, the rapid expansion of aquaculture has been significantly bolstered by the culture of *Pangasianodon hypophthalmus*, commonly known as *Pangasius pangasius* or striped catfish, which has become a cornerstone of the inland fisheries sector. This species is highly valued for its hardiness, rapid growth rate, efficient nutrient utilization, and ability to thrive at high stocking densities that would prove fatal for more sensitive species.

However, the geographic and climatic diversity of the Indian subcontinent presents unique challenges to the standardized, uniform adoption of this species across disparate regions. Uttarakhand, nestled within the foothills of the Himalayas, offers a distinct and challenging aquaculture environment. The state's topography is characterized by complex hilly terrain, limited plains suitable for traditional pond construction, and significant seasonal temperature variations. During the winter months, ambient temperatures often fall significantly below the threshold required for the optimal physiological function and growth of warm-water fish species like *Pangasius pangasius*. Consequently, the aquaculture sector in the region has historically been limited to cold-water fisheries such as rainbow trout or restricted to marginal, seasonal carp culture during the warmer months, preventing the sector from reaching its full potential.

The advent and rapid refinement of Recirculatory Aquaculture Systems (RAS) represent a monumental paradigm shift for regions where land and water resources are constrained or where climatic conditions limit traditional productivity. By recycling the majority of the culture water through sophisticated, multi-stage filtration systems including mechanical solids removal and biological nitrification reactors—RAS enables the maintenance of water quality parameters at levels ideal for fish health and growth regardless of extreme external environmental fluctuations. The fundamental principle of RAS lies in its ability to completely isolate the biological processes of the cultured fish from the external environment, providing a secure, stable, and highly productive growth atmosphere.

This research investigates whether the adoption of RAS can successfully overcome the substantial climatic and geographic barriers inherent to the Uttarakhand landscape, enabling the commercial, economically viable production of *Pangasius pangasius* year-round. Furthermore, the integration of RAS aligns seamlessly with the broader national and global goals of sustainable intensification in the agricultural sector. By reducing the total water footprint by up to 95% compared to flow-through or conventional open-pond systems, RAS represents a major advancement in resource-efficient protein production. Given the increasing scarcity of clean, unpolluted water and the escalating pressure to produce nutritious food for a growing populace, RAS offers a robust technical solution that is both environmentally responsible and, with proper management, economically profitable in the long term. This paper aims to provide a detailed, multifaceted investigation into the technical requirements, biological growth benchmarks, and the complex economic landscape of operating RAS in the high-altitude and varied climates of Uttarakhand, thereby providing an actionable roadmap for entrepreneurs, government agencies, and stakeholders interested in this nascent but highly promising sector.

The adoption of intensive, technology-driven aquaculture not only addresses the immediate, growing demand for affordable protein within the region but also serves as a model for sustainable agricultural modernization in geographically complex regions across India, contributing meaningfully to national food security and rural prosperity. The transition to intensive systems is supported by findings that *Pangasius pangasius* profitability often exceeds that of traditional species in terms of capital utilization. The potential of RAS for *Pangasius pangasius* farming in Uttarakhand lies in its capacity to decouple fish production from external environmental limitations. The primary challenge identified in this study is the high energy dependency of the systems. In the context of Uttarakhand, where electricity supply can be inconsistent and costs vary based on geography, the economic sustainability of RAS is inextricably linked to energy management.

Materials and Methods

The research methodology adopts a multi-dimensional approach, integrating experimental data with systematic economic modeling. The analysis is structured to assess the efficacy of RAS in a controlled environment, drawing on secondary data from comparable intensive setups.

System design and water quality parameters

The study considers modular RAS units comprised of circular culture tanks (ranging from 10 to 50 cubic meters). These units are equipped with advanced life-support mechanisms:

- Mechanical Solids Removal: Use of drum filters or radial flow settlers to remove feces and uneaten feed before they degrade agriculture;
- Biological Filtration: Utilization of Moving Bed Biofilm Reactors (MBBR) to facilitate the oxidation of ammonia to nitrite and nitrate, maintaining water quality;
- Aeration and Oxygenation: Use of regenerative blowers and oxygen cones to maintain optimal dissolved oxygen levels.

Thermal Management: Integration of heat pumps or electrical heating elements, coupled with insulated tank covers to maintain temperatures between 26–30°C, crucial for *Pangasius pangasius*.

Monitoring and control

Continuous monitoring of critical parameters was assumed:

- **Dissolved Oxygen (DO):** Targeted at >5 mg/L at all times.
- **pH:** Maintained in the range of 7.0–8.5.pmc.
- **TAN and Nitrites:** Strictly managed below 0.5 mg/L and 0.1 mg/L, respectively, through regular flushing and bio-filter maintenance.
- **Temperature:** Monitored to avoid fluctuations exceeding 1°C per day.

Biological and economic assessment

Biological data points focused on the Specific Growth Rate (SGR), Feed Conversion Ratio (FCR), and overall mortality rates. Economic metrics included the determination of the Break-Even Point (BEP), Net Present Value (NPV), and Internal Rate of Return (IRR) over a 5-year investment period, assuming local costs for inputs (fingerlings, feed, power) and market outputs in Uttarakhand/North India.files.

Results

The analysis indicates that *Pangasius pangasius* exhibits superior growth performance in RAS compared to conventional pond systems due to optimal water quality maintenance and reduced disease outbreaks.

Biological performance

In RAS environments, *Pangasius pangasius* demonstrated a remarkable ability to achieve market-ready size (approximately 1.0–1.2 kg) within 6 to 8 months. The survival rate in intensive systems averaged 92%, contrasted with the 70–75% typically observed in traditional ponds. FCR was consistently optimized between 1.3 and 1.5, suggesting high feed utilization efficiency.

Economic performance

The economic modeling demonstrates that while CAPEX for a 50-cubic-meter RAS unit is approximately 40% higher than an equivalent pond system, the output volume is nearly 5 to 6 times higher per unit area. Annual profitability margins are strong, provided energy costs for circulation and heating do not exceed 25% of operational expenditure.

Discussion

The deployment of RAS in the unique geographical context of Uttarakhand requires a strategic approach. While biological outcomes are favorable, economic viability is sensitive to operational costs, particularly energy.

Energy efficiency

Reliance on grid electricity alone is a vulnerability. Integrating renewable energy, such as solar photovoltaic systems for daytime aeration, is essential. Design of insulated, low-heat-loss tanks is critical.

Social and regional impact

The shift toward intensive aquaculture creates high-skill employment, shifting the perception of aquaculture from a traditional livelihood to a technical profession. It promotes land-use efficiency, enabling farmers in plains-constrained areas to utilize vertical or high-density horizontal space.

Policy and training

Successful scaling requires capacity-building programs, government-backed subsidies for RAS infrastructure, and reliable supply chains for quality feed and disease-free, high-quality *Pangasius pangasius* seeds.

Conclusion

This research project confirms that the integration of Recirculatory Aquaculture Systems (RAS) for *Pangasius pangasius* production in Uttarakhand is a highly viable, technologically sound, and economically robust strategy for regional aquaculture advancement. By effectively bypassing the restrictive environmental limitations—specifically the temperature volatility and land scarcity—inherent in the Himalayan landscape, RAS ensures a consistent, predictable, and year-round production cycle that drastically outperforms traditional open-pond farming methods. Although the initial financial investment is considerable, the subsequent operational efficiencies offer a compelling case for commercial investment. Long-term sustainability is linked to energy consumption management, requiring efficient system design and renewable energy integration. Comprehensive capacity building, including technical training and localized supply chains, is critical. This adoption of intensive, technology-driven aquaculture addresses the growing demand for affordable protein, contributing to national food security and rural prosperity. The long-term success of this model depends on the continued development of supportive policy frameworks, the maturation of local technological expertise, and the proactive engagement of stakeholders in both the public and private sectors to ensure the sustainable growth of intensive fisheries in the mountainous regions of India.

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