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Nutritious Pond System- An Innovative Approach for Sustainable Production

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The Nutritious Pond System (NPS) is an emerging ecological approach aimed at improving nutrient use efficiency and sustainability in aquaculture. Conventional pond systems are often characterized by inefficient nutrient utilization, leading to waste accumulation, environmental degradation, and reduced productivity. The NPS addresses these limitations by promoting internal nutrient recycling and enhancing natural food production within the pond ecosystem. This system is based on the principle of "feeding both the pond and the cultured organism," where feed inputs are strategically modified by reducing protein levels and increasing carbohydrate content, including non-starch polysaccharides. These carbohydrates act as indirect carbon sources through excretion, stimulating heterotrophic microbial activity and strengthening the natural food web. The integration of microbial processes, phytoplankton, zooplankton, and benthic organisms enhances nutrient assimilation and improves water quality. Comparative analysis indicates that NPS can maintain growth performance despite reduced protein input, while improving feed conversion ratio, nitrogen retention, and biomass production. Additionally, the system reduces feed costs and environmental impacts, contributing to higher economic returns. Overall, the Nutritious Pond System represents a practical and scalable strategy for sustainable aquaculture, offering a balance between productivity, environmental conservation, and resource efficiency.

Introduction

Aquaculture is one of the fastest-growing food production sectors globally and plays a vital role in ensuring food security. However, conventional pond-based systems often suffer from **poor nutrient utilization**, where a large proportion of feed inputs is lost as waste, leading to water quality deterioration and environmental concerns (Dossou *et al.*, 2026). These inefficiencies arise mainly due to inadequate nutrient recycling and underutilization of the pond's natural productivity. In many systems, the pond is treated merely as a holding unit rather than an active biological system capable of generating its own food resources (Joffre & Verdegem, 2019). To address these limitations, the concept of **ecological intensification** has gained attention, focusing on improving production through better use of natural processes rather than increasing external inputs. In this context, the **Nutritious Pond System (NPS)** has emerged as a promising approach. The NPS is based on the principle of *"feeding both the* *pond and the cultured organism,"* where nutrient inputs are managed to stimulate microbial activity and natural food production. By enhancing nutrient recycling and improving internal ecosystem functioning, the system converts waste into valuable biomass, thereby increasing feed efficiency and reducing environmental impact (Hermsen, 2020; Campanati *et al.*, 2021).

Concept and Principle of the Nutritious Pond System

The Nutritious Pond System represents a shift from input-driven aquaculture to **process-driven aquaculture**. Instead of focusing solely on feeding the cultured species, the system recognizes the pond as a dynamic ecosystem where nutrients can be continuously recycled. In conventional systems, nutrients from feed are often lost due to inefficient assimilation. In contrast, the NPS enhances the pond's biological processes so that these nutrients are retained and transformed into natural food such as phytoplankton, zooplankton, microbial biomass, and detritus. A key aspect of the system is the regulation of the **carbon-to-nitrogen (C:N) ratio**, which promotes the growth of beneficial microorganisms. These microorganisms convert dissolved nutrients into biomass that can be consumed by cultured species, thereby improving overall system efficiency. Thus, the NPS does not depend on additional inputs but rather on **improving how existing nutrients are utilized within the pond ecosystem**. Overview of nutritious pond system shown in Fig. 1.

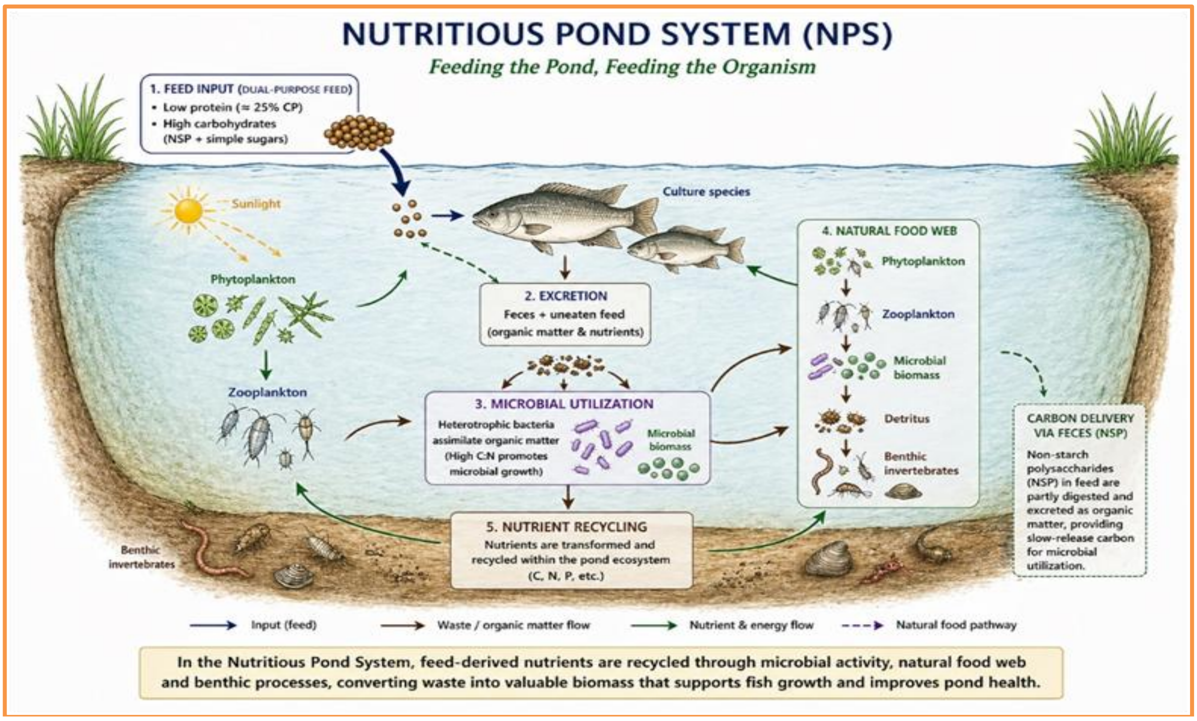

Figure 1: Overview of Nutritious Pond System

Feed Strategy and Carbon Delivery Mechanism

An important and distinctive feature of the Nutritious Pond System lies in its approach to feed formulation and carbon management. In conventional aquaculture, feeds are typically formulated with **high protein content** to meet the nutritional demands of cultured species. However, this often results in inefficient nitrogen utilization, leading to increased waste generation and environmental stress. In contrast, the Nutritious Pond System adopts a **strategic shift in feed composition**, where dietary protein levels are reduced and partially replaced with carbohydrate-rich ingredients. These carbohydrates may include both **rapidly fermentable carbon sources** (such as molasses or simple sugars) and **complex carbohydrates**, particularly non-starch polysaccharides (NSPs), which are present in plant-based feed ingredients. Dietary protein levels can be reduced from around 32% to 25% without significantly affecting growth performance (Kabir *et al.*, 2019). This modification serves a dual purpose. First, a portion of these carbohydrates is directly utilized by the cultured organisms for energy. Second, and more importantly, a significant fraction is excreted as organic matter, which becomes available for microbial utilization within the pond. This process effectively introduces carbon into the system **indirectly through animal excretion**, rather than through external application. This mechanism represents a key difference from systems such as Bio floc Technology, where carbon sources are typically added directly into the water to manipulate the C:N ratio. In the Nutritious Pond System, carbon is delivered in a more **distributed and biologically mediated manner**, enhancing its integration into the pond ecosystem. The continuous release of organic carbon through excreta supports heterotrophic microbial growth, promotes nutrient assimilation, and strengthens the natural food web. As a result, the pond ecosystem becomes more efficient in recycling nutrients, converting waste into microbial and planktonic biomass that can be re-utilized by cultured species. This approach not only improves nutrient use efficiency but also contributes to the overall stability and sustainability of the system.

Biological and Biogeochemical Mechanisms in the Nutritious Pond System

The effectiveness of the Nutritious Pond System (NPS) is fundamentally governed by a series of interconnected biological and biogeochemical processes that regulate nutrient transformation, energy flow, and biomass production within the pond ecosystem. Unlike conventional systems where nutrients are inefficiently utilized, the NPS enhances internal nutrient cycling through the coordinated activity of microorganisms, primary producers, and higher trophic levels.

Carbon Dynamics and C:N Ratio Regulation

One of the central mechanisms driving the NPS is the regulation of the **carbon-to-nitrogen (C:N) ratio**, which determines the dominant metabolic pathways within the pond ecosystem. Conventional aquaculture feeds are typically protein-rich and carbon-limited, resulting in inefficient nitrogen assimilation and accumulation of toxic nitrogenous compounds.

The addition of carbon sources—either through feed formulation or external inputs such as carbohydrates—shifts the system toward **heterotrophic dominance**, where bacteria utilize available nitrogen to synthesize microbial biomass (Kabir *et al.*, 2019). When the C:N ratio exceeds critical thresholds (generally above 10–15), heterotrophic bacteria become more competitive than autotrophic nitrifiers, leading to rapid immobilization of dissolved nitrogen into microbial cells.

This process offers multiple advantages:

- Reduction of toxic ammonia and nitrite concentrations
- Conversion of waste nutrients into microbial protein
- Enhancement of natural food availability for cultured species

By effectively balancing carbon and nitrogen inputs, the NPS promotes a more efficient and stable nutrient cycling process.

Microbial Loop and Natural Food Web Enhancement

A key feature of the Nutritious Pond System is the stimulation of the **microbial loop (Fig. 2)**, which plays a critical role in recycling nutrients and supporting higher trophic levels. The microbial loop involves the uptake of dissolved organic matter by bacteria, followed by its transfer through protozoa and zooplankton to larger consumers.

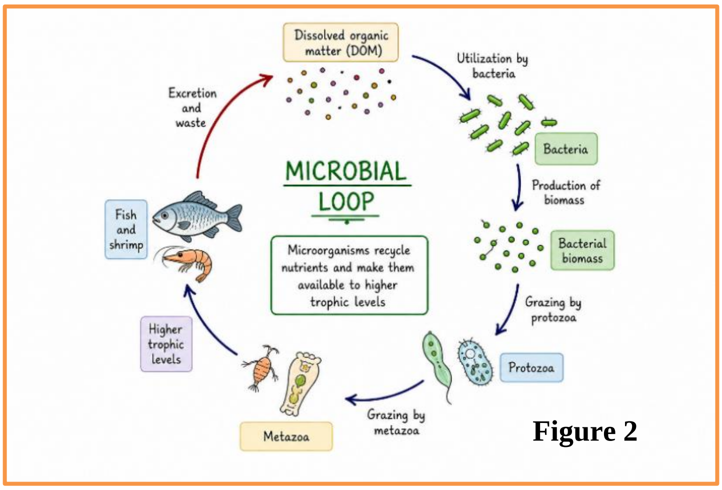

Figure 2

In pond ecosystems, microbial biomass serves as a direct or indirect food source for cultured species such as shrimp and fish. Research indicates that heterotrophic bacterial biomass, along with phytoplankton and detritus, contributes significantly to the nutritional intake of aquaculture species (Hermsen, 2020). This is particularly important in semi-intensive systems, where natural food can supplement formulated feed and improve overall feed conversion efficiency. Additionally, the composition of the food web is influenced by nutrient availability and environmental conditions. For instance, increased carbon inputs favour bacterial production, while balanced nutrient conditions support the growth of high-quality phytoplankton such as diatoms, which are rich in essential fatty acids. These components enhance the nutritional quality of the food web and improve growth performance in cultured organisms.

Nitrogen Transformation Processes

Nitrogen cycling is a critical component of pond ecology and directly influences water quality and productivity. In aquaculture systems, nitrogen is introduced primarily through protein-rich feed and is subsequently transformed through several pathways, including:

- **Ammonification**: Conversion of organic nitrogen into ammonia
- **Nitrification**: Oxidation of ammonia to nitrite and nitrate by autotrophic bacteria
- **Denitrification**: Reduction of nitrate to nitrogen gas under anaerobic conditions
- **Assimilation**: Uptake of inorganic nitrogen by phytoplankton and bacteria

In conventional systems, these processes often occur inefficiently, leading to the accumulation of toxic intermediates such as ammonia and nitrite. However, in the NPS, enhanced microbial activity and balanced nutrient conditions facilitate rapid nitrogen assimilation into biomass, thereby minimizing toxicity and improving water quality (Joffre & Verdegem, 2019).

Species Suitable For Nutritious Pond System

The selection of appropriate species is a critical factor determining the success of the Nutritious Pond System (NPS). Since the NPS is designed to enhance microbial biomass, phytoplankton, zooplankton, and detritus-based food webs, species that are capable of directly or indirectly utilizing these natural food resources are most suitable. In this context, omnivorous and herbivorous species are considered ideal candidates for NPS. These species possess the ability to efficiently exploit a wide range of natural food items, including phytoplankton, bio flocs, detritus, and microbial aggregates. Their flexible feeding behaviour allows them to utilize nutrients recycled within the pond, thereby maximizing overall system productivity and improving nutrient use efficiency. The NPS can be successfully applied across extensive and semi-intensive systems, provided that species selection aligns with the availability of natural food and the system's nutrient dynamics.

Several species groups are particularly suitable for cultivation in the Nutritious Pond System:

Species	Scientific Name	Feeding Habit
Nile tilapia	*Oreochromis niloticus*	Omnivore (plankton feeder)
Common carp	*Cyprinus carpio*	Omnivore (benthic feeder)
Grass carp	*Ctenopharyngodon idella*	Herbivore
Silver carp	*Hypophthalmichthys molitrix*	Filter feeder
Rohu	*Labeo rohita*	Column feeder
Pacific white shrimp	*Litopenaeus vannamei*	Omnivore (detritus feeder)
Milkfish	*Chanos chanos*	Herbivore/Omnivore
Giant river prawn	*Macrobrachium rosenbergii*	Omnivorous/Detritivorous

In contrast, strictly carnivorous species are generally not suitable for the Nutritious Pond System. Carnivorous fish require high-protein diets and depend largely on formulated feeds rather than natural productivity

Growth Performance and Production Efficiency

"A comparative evaluation of growth performance, nutrient utilization, and economic efficiency between conventional pond systems and the Nutritious Pond System (NPS) is presented in Table 1. The data indicate that reducing dietary protein levels while increasing carbon availability does not compromise growth, but instead enhances nutrient recycling and natural food contribution. This results in improved biomass production, better feed efficiency, and higher economic returns. Overall, the NPS demonstrates superior performance through optimized internal nutrient

Table 1- A comparative evaluation of growth performance, nutrient utilization, and economic efficiency between conventional pond systems and the Nutritious Pond System

Parameter	Conventional System	NPC System	Interpretation
Protein level	~32% CP	~25% CP	Protein reduced
C:N ratio	~8	~11	More carbon availability
Biomass production	399 g/m^2	459 g/m^2	↑ ~15% production
Biomass gain range	347–451 g/m^2	360–559 g/m^2	Higher yield potential
N from food web	~2.2–2.9 g/m^2	~4.2–6.6 g/m^2	Strong food web role
Survival	~74%	~74%	No difference
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Survival	~74%	~74%	No difference
Growth (weight gain)	Lower	Slightly higher	Improved growth trend
FCR	~1.02	~0.88–1.01	Better feed efficiency
Nitrogen retention	51–52%	~71%	Major improvement
N input via feed	Higher	Lower	Efficient use of feed
N gain in fish	Lower	Higher	More biomass per N input
Natural food contribution	Lower	Higher (major contributor)	Key mechanism
Feed cost	Higher	Lower	Protein reduction
Gross margin	1067 USD/ha	2076 USD/ha	↑ ~95%
Benefit-cost ratio	1.29	1.57	↑ ~22%

Comparison with Other Aquaculture Systems

"A comparative overview of conventional pond systems, Bio floc Technology (BFT), and the Nutritious Pond System (NPS) is presented in Table 2. While conventional systems are largely input-driven and inefficient in nutrient utilization, BFT represents an intensive, highly controlled microbial approach. In contrast, the NPS integrates ecological processes with feed-based carbon management, promoting balanced nutrient recycling within the pond ecosystem. This comparison highlights the unique position of NPS as a sustainable and adaptable system that combines efficiency with lower operational complexity."

Table 2- A comparative overview of conventional pond systems, Bio floc Technology (BFT), and the Nutritious Pond System

Aspect	Conventional System	Bio floc Technology (BFT)	Nutritious Pond System (NPC)
Core Principle	Direct feeding system	Engineered microbial system	Ecological nutrient recycling system
Nutrient Pathway	Feed → Fish → Waste	Feed → Waste → Bacteria → Fish	Feed → Feces → Food web → Fish
Carbon Source	Limited	External (molasses, starch)	Internal (feces via NSP)
C:N Management	Not controlled	Actively maintained (10–20)	Controlled via feed formulation
Carbon Delivery Mode	None	Direct water addition (fast)	Slow-release via feces
Microbial Community	Weak	Bacteria-dominated	Balanced (algae + bacteria + benthos)
Food Web Structure	Poorly developed	Simplified (bacterial loop)	Complex & diverse
Natural Food Type	Minimal plankton	Bio floc (bacterial biomass)	Plankton, algae, detritus, microbes
Feed Strategy	High protein diets	Protein reduced + external carbon	Low protein + high NSP (dual-purpose feed)
Aeration Requirement	Moderate	**Very high (continuous)**	Low–moderate
Energy Demand	Low	High	Low
Waste Fate	Accumulates	Converted to flocs	Recycled into food web
System Control	Passive but inefficient	Highly controlled & intensive	Self-regulated ecosystem
Production Efficiency	Moderate	High	High (with lower inputs)
Nutritional Quality of Natural Food	Low	Moderate	High (algae-based + diverse)
Environmental Impact	High waste output	Lower discharge but energy intensive	Low waste + eco-friendly
Scalability	Widely practiced	Intensive systems only	Semi-intensive adaptable

Environmental and Economic Benefits of the Nutritious Pond System

The Nutritious Pond System (NPS) enhances sustainability by improving **nutrient recycling and reducing environmental impacts**. More than 70% of nitrogen can be retained in the system. Efficient microbial assimilation minimizes nutrient discharge, thereby lowering risks of eutrophication and water pollution (Campanati *et al.*, 2021).

The system also contributes to **reduced greenhouse gas emissions** by improving feed efficiency and limiting organic waste accumulation (Zhang *et al.*, 2024).

Economically, the NPS reduces **feed costs** through enhanced natural food production and improved feed conversion efficiency (Hermsen, 2020). Lower dependency on external inputs and improved survival rates contribute to higher profitability.

Overall, the NPS offers a cost-effective and environmentally sustainable approach to aquaculture, aligning with circular bioeconomy principles.

Conclusion

The Nutritious Pond System is not a rigid or stand-alone production model like Recirculatory Aquaculture Systems or Biofloc Technology. Instead, it represents a conceptual and ecological improvement of existing aquaculture practices, particularly those already followed by farmers in extensive and semi-intensive pond systems. In most conventional ponds, the major limitation is not the lack of inputs, but the inefficient utilization of nutrients, where a significant portion of feed-derived nutrients is lost or remains unutilized within the system. The Nutritious Pond System addresses this fundamental issue by focusing on correcting pond ecology rather than increasing external inputs. By enhancing natural processes such as microbial activity, nutrient recycling, and food web dynamics, the system enables the pond to reuse its own nutrients more effectively. This transforms the pond from a passive rearing unit into an active, self-sustaining ecosystem that supports both productivity and environmental stability. Thus, the essence of the Nutritious Pond System lies in making the pond healthier and more efficient, rather than making it more complex or input-intensive. It offers a practical and adaptable approach that can be integrated into existing farming systems, helping farmers achieve better production, reduced costs, and improved sustainability without drastic changes to their current practices.

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