

Biofloc Technology: A Sustainable Method for Finfish and Shellfish Farming

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Abstract

Seafood diet is capable of addressing global increase in malnutrition concerns. More than 50% of human seafood consumption was satisfied by aquaculture production. Biofloc system is one such technique, that facilitates high-density aquaculture production with enhanced feed use efficiency. Biofloc technology involves manipulation of heterotrophic microbial communities, to aggregate as flocs that suspend in water and assimilate dissolved nitrogenous waste (Total ammonia nitrogen) into protein-rich microbial biomass. Here, the bioflocs serve as a sustainable water treatment mechanism under zero or minimal water exchange conditions and as a supplementary feed source. Additionally, the immune system and disease resistance of finfish and shellfish can be strengthened by the presence of beneficial microbes. Overall, bioflocs technology presents a viable strategy for effective and sustainable aquaculture development with least environmental impact. This article provides better understanding on working principles, disease management, applications, advantages and limitations of BFT

Introduction

In 2024, global aquaculture production exceeds 122 million tons. The annual growth of aquaculture production increases at a rate 5.8%, significantly outpacing capture fisheries (FAO, 2025). Despite this rapid growth, conventional semi-intensive pond systems widely used for shrimp (*Litopenaeus vannamei*) or tilapia (*Oreochromis niloticus*) farming rely on 30–50% daily water exchange to maintain water quality. These practices discharge substantial quantities of nitrogenous waste, estimated at 10–20 kg total ammonia nitrogen (TAN) per hectare per production cycle, contributing to coastal eutrophication and environmental degradation in nearly 20% of tropical aquatic ecosystems (Crab et al., 2012; De Schryver et al., 2008).

Biofloc Technology (BFT), often referred to as a “new blue revolution” in aquaculture, originated in the 1970s at the French Research Institute for Exploitation of the Sea (IFREMER) as an experimental zero-water-exchange system for tilapia polyculture (Emerenciano et al., 2017). The concept was later advanced by Yoram Avnimelech in the 1990s, who emphasized

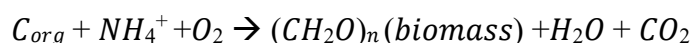
the importance of microbial management and nutrient recycling in aquaculture systems. Commercial adoption accelerated during the 2000s, particularly in Brazil, where super-intensive shrimp farming systems were developed. Today, BFT has been widely adopted across major aquaculture-producing regions, including Asia (India and Vietnam), Latin America (Ecuador), and parts of Africa. It supports over 1.5 million tonnes of annual shrimp production and aligns closely with global sustainability initiatives such as FAO's Blue Growth strategy and the United Nations Sustainable Development Goal 14 (Life Below Water) (Emerenciano et al., 2017; FAO, 2025). Despite the advantages, BFT face challenges such as high energy requirements, system management complexity, and limited species diversification. This article provides an overview on nutrient cycling, microbial dynamics, design, disease management, applications, advantages and limitations of BFT.

Nutrient cycling and Microbial dynamics in BFT

The core purpose of BFT revolves around efficient nitrogen management. Aquaculture species excrete approximately 25–30% of dietary protein as total ammonia nitrogen (TAN), primarily through gills (60–70%) and feces (30–40%) (Avnimelech, 2015). Without proper control, TAN concentrations can exceed toxic thresholds (0.5–1 mg/l of un-ionized ammonia), adversely affecting aquatic organisms.

BFT system maintain TAN levels below 0.8 mg/l by increasing the carbon-to-nitrogen (C:N) ratio between 12:1 and 20:1. Here addition of carbon sources such as molasses, rice bran, or glycerol (Crab et al., 2012), promote the rapid growth of heterotrophic bacteria, such as *Bacillus subtilis* and *Pseudomonas* species. These bacteria assimilate ammonia into microbial biomass (de schryver et al., 2008).

The simplified biochemical reaction can be expressed as:



This process yields approximately 0.4–0.7 kg of microbial protein per kilogram of carbon added (Avnimelech, 2015). Carbon dosing is calculated based on feed input and nitrogen content at a given time to maintain the desired C:N ratio.

In addition to heterotrophic assimilation, autotrophic nitrification also occurs, where ammonia is oxidized into nitrite and nitrate by nitrifying bacteria such as *Nitrosomonas sp* and *Nitrobacter sp* (Boyd, 2020). Furthermore, anaerobic denitrification within the floc matrix converts nitrate into nitrogen gas, improving nitrogen removal efficiency to 75–90%, compared to 40–50% in conventional systems (Crab et al., 2012). Along with TAN, soluble phosphorus levels were reduced upto 90%, as microbes take up and store phosphorus as polyphosphates (De schryver et al., 2008). These combined processes ensure low effluent discharge, typically

maintaining TAN below 1 mg/l and biological oxygen demand (BOD) below 20 mg/l, while simultaneously generating microbial biomass containing 30–60% crude protein (Emerenciano et al., 2017).

Bioflocs reduce reliance on commercial feed by replacing 30–40% of dietary protein requirements. This microbial protein enhances digestibility upto 85%, improves feed conversion efficiency, and increases growth performance by 15–25% for cultured aquatic organism (Crab et al., 2012). Shrimp directly graze on these flocs, achieving feed conversion ratio (FCR) values close to 1.2, while tilapia utilize microbial fermentation in the gut for improved nutrient absorption (De Schryver et al., 2008).

Maintaining optimal floc composition with low fiber content and balanced suspended solids is essential for maximizing feed intake and system efficiency.

Biofloc nutritional composition compared to commercial feed

Component	Biofloc (%)	Commercial feed (%)	Functional contribution
Crude protein	30-60	30-40	Major protein source
Lipids	1-5	6-8	Essential fatty acids
Fiber	5-15	3-5	Aids digestion
Ash	15-25	10-12	Mineral supply

This highlights the role of BFT in reducing aquaculture production costs, while enhancing sustainability and productivity in aquaculture systems (Avnimelech, 2015; Crab et al., 2012).

Microbial dynamics in BFT systems

Bioflocs are dense, suspended aggregates ranging from 50 to 500 µm in diameter and consisting of complex microbial communities with densities reaching 10^9 – 10^{12} cells per milliliter (De schryver et al., 2008). These communities are dominated by proteobacteria (45–50%), firmicutes (20–25%), and bacteroidetes (15–20%), with heterotrophic bacteria exhibiting significantly faster growth rates than autotrophic organisms (Crab et al., 2012).

Biofloc microbial communities evolve through distinct phases:

- *Startup phase (0–21 days)*: Initial establishment of nitrifying bacteria and microbial populations ($\sim 10^7$ cells/ml). Probiotic bacteria such as *Bacillus* spp. Are often introduced to accelerate system stabilization (Emerenciano et al., 2017).

- *Growth phase (21–45 days)*: rapid proliferation of heterotrophic bacteria (up to 10^{10} cells/ml) under high C:N conditions, leading to efficient nitrogen assimilation (Avnimelech, 2015).
- *Mature phase (>45 days)*: development of a stable ecosystem where protozoa (e.g., *Vorticella*, *paramecium*) regulate bacterial populations and serve as crucial link in microbial food web. On the other hand, microalgae (e.g., *Chlorella*) contribute to oxygen production and nutrient cycling (Crab et al., 2012). The protozoa and microalgae are not necessarily added on initial colonization but are introduced via the water source and thrive due to favourable conditions in BFT system.

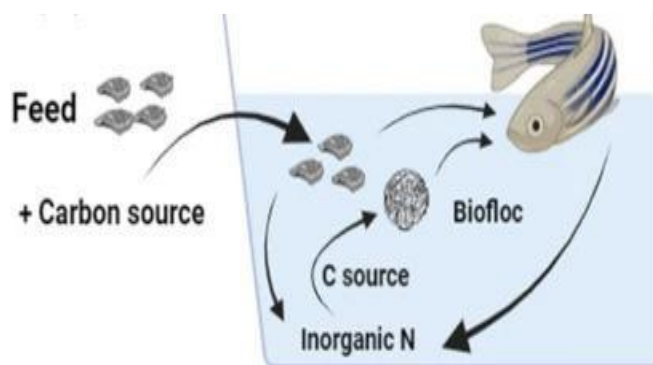


Figure 1: Nutrient cycling in BFT

The following biological interactions contribute to system stability:

Floc formation: microorganisms produce extracellular polymeric substances (EPS), enhancing aggregation and structural stability of bioflocs (De schryver et al., 2008).

Trophic regulation: protozoa and microalgae control bacterial density, preventing excessive microbial growth and oxygen depletion respectively (Emerenciano et al., 2017).

Pathogen suppression: beneficial microbes inhibit pathogenic bacteria such as *Vibrio* species through competitive exclusion and antimicrobial compound production (Crab et al., 2012).

Optimal environmental conditions including salinity (5–35 ppt), pH (7.5–8.5), and adequate aeration are essential for maintaining microbial balance and system efficiency (Boyd, 2020). However, excessive floc accumulation leads to the risk of hypoxia.

Phase	Heterotrophs (%)	Autotrophs (%)	Protozoa (Cells /ml)	Dominant role
Startup	30-40	40-50	10^4	Biofilter (Biofilm) establishment

Growth	70-80	10-15	10 ⁶	Nitrogen assimilation
Mature	60-70	15-20	10 ⁷	Oxygen and nutrient balance
Overload	40-50	5-10	10 ⁵	Risk of hypoxia

Overall, the microbial consortium in biofloc systems not only maintains water quality but also contributes 25–50% of the nutritional requirements of cultured species, significantly reducing feed costs and improving sustainability (Avnimelech, 2015; Crab et al., 2012).

BFT design and Management

The design of a biofloc system mainly includes culture tanks, aeration systems, and proper water circulation. Culture tanks are usually circular because they allow better mixing of water and prevent accumulation of waste at the bottom. These tanks are constructed using materials such as concrete, fiberglass, or high-density polyethylene (HDPE). (Crab et al., 2012).

Aeration is a crucial part of the system design because microorganisms and cultured aquatic animals require sufficient dissolved oxygen (DO). Aeration devices such as air blowers, paddle wheel aerators, and diffusers are used to maintain DO levels above 5 mg/L and keep bioflocs suspended in the water column (Hargreaves, 2006).

Maintaining an appropriate carbon-to-nitrogen (C:N) ratio is another important design factor in BFT. This promotes growth of heterotrophic bacteria that converts toxic ammonia produced from fish waste and uneaten fish feed into microbial biomass. This microbial biomass perpetuates as bioflocs and eventually improves water quality (Avnimelech, 1999).

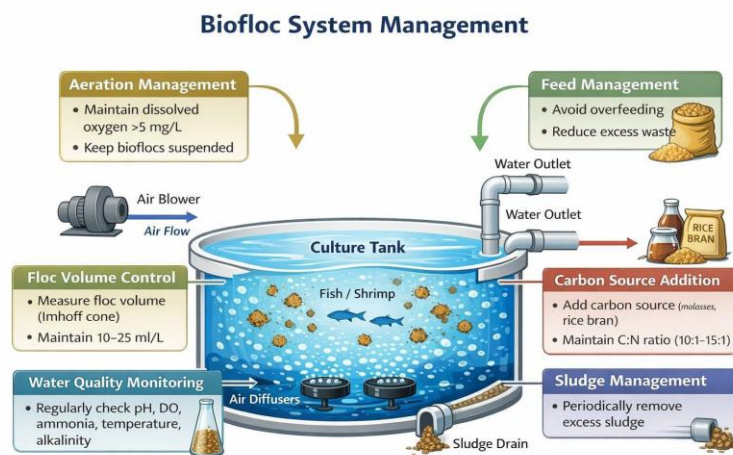


Figure 2: Biofloc management system

Proper management is essential to maintain the stability and efficiency of biofloc systems. Regular monitoring of water quality parameters such as temperature, pH, dissolved oxygen, ammonia, and alkalinity is necessary to maintain a stable biofloc environment. Maintaining proper alkalinity (Calcium Carbonate > 120 mg/L) and controlling floc concentration help support microbial activity and ensure healthy growth of aquatic species (Hargreaves, 2006). Here, proper aeration is also necessary to avoid oxygen depletion and stress in cultured organisms (Emerenciano et al., 2013). Bioflocs contain proteins, lipids, and vitamins that serve as an additional natural food source for fish and shrimp, thereby reducing feed costs (Crab et al., 2012). However, overfeeding should be avoided because it increases organic waste and ammonia levels in the water.

Disease management in BFT based aquaculture

One of the major advantages of biofloc technology is its ability to reduce the occurrence of diseases in aquaculture systems. Beneficial microorganisms present in bioflocs compete with pathogenic bacteria for nutrients and space, thereby limiting the growth of harmful pathogens. This microbial competition helps reduce disease outbreaks and improves the overall health of cultured organisms (Crab et al., 2012). Bioflocs also contain nutrients and bioactive compounds that improve the immune response of fish and shrimp, making them more resistant to infections (Emerenciano et al., 2013). Improved water quality reduces environmental stress in cultured species, which further enhances their resistance to diseases (Hargreaves, 2006).

For instance, BFT facilitated super-intensive shrimp farming in Brazil, to address disease outbreaks such as white spot syndrome virus (WSSV), This elevated shrimp production levels to 5–10 kg/m³ with minimal environmental discharge (Avnimelech, 2015; Emerenciano et al., 2017).

Applications of BFT in sustainable aquaculture

Biofloc technology can be widely adapted across different production systems and species due to its flexibility and scalability (Emerenciano et al., 2017). Shrimp (*Litopenaeus vannamei*) is often cultured, with stocking densities of 300–1,000/m³ and production yields of 4–8 kg/m³, particularly in India, Vietnam, and Ecuador. Tilapia (*Oreochromis niloticus*) is suitable for high-density monoculture and polyculture systems. This achieves production level between 15–25 kg/m³ annually, often integrated with aquaponics systems (De Schryver et al., 2008). Other species including catfish (*Clarias gariepinus*), carp (*Cyprinus carpio*), and emerging marine species such as seabass and eel are cultured in hybrid systems combining BFT and recirculating aquaculture systems (RAS) (Boyd, 2020). BFT can be applied in

integrated systems like aquaponics, hatcheries, and rural small-scale farming systems, supporting livelihood diversification and food security (Emerenciano et al., 2017).

Advantages of BFT in sustainable aquaculture

Biofloc technology (BFT) align with multiple global sustainability goals, including efficient resource utilization, improved biosecurity, and enhance economic returns in intensive aquaculture systems (Emerenciano et al., 2017; Crab et al., 2012). The details are given as follows.

- BFT systems require < 5% water exchange per day and enables high production densities (5–10 kg/m³) in shrimp culture (Emerenciano et al., 2017).
- It reduces feed conversion ratios (FCR) to approximately 1.1–1.4 compared to 1.6–2.0 in conventional systems (Avnimelech, 2015).

$$\text{Feed conversion ratio} = \frac{\text{Total feed consumed}}{\text{Total body weight gained}}$$

$$\text{Total body weight gained} = \text{Final weight} - \text{Initial weight}$$

- Further, it immobilizes 80–95% of TAN and phosphorus, reducing effluent discharge and maintaining biological oxygen demand (BOD) below 20 mg/l, thereby minimizing eutrophication risks (De Schryver et al., 2008).
- Presence of beneficial microbes in BFT enhances immune response and reduces disease outbreaks by 50–70%, often eliminating the need for antibiotics (Crab et al., 2012).
- BFT systems demonstrate favourable benefit–cost ratios (1.8–2.5) and return on investment within 18–24 months due to reduced feed and water costs (Boyd, 2020).

Limitations of BFT

Despite its advantages, BFT face several biological, environmental, socio-economic, technical, and species-specific constraints that limit its large-scale adoption.

i) Biological and environmental Challenges

High microbial imbalance and poor system control can result in nitrate accumulation and reduced water quality stability. Seasonal fluctuations, especially in open or semi-open systems, can significantly affect production efficiency and may lead to crop loss during unfavorable climatic conditions (Avnimelech, 1999).

For instance, at low level, filamentous bacteria assist in forming stable and nutritious bioflocs. However, on excessive growth due to low oxygen or high carbon loading leads to poor settling or sludge bulking, where flocs become too light to settle properly. In addition, filamentous bacteria overgrowth disrupts floc structure, reduces oxygen transfer efficiency, impair nutrient cycling and poor water quality. (Avnimelech, 2012).

ii) Socio-economic and Production Challenges

With the global population projected to reach nearly nine billion by 2050, the demand for fish as a major protein source is continuously increasing. However, food insecurity and malnutrition remain major global concerns, with over 500 million people still undernourished. Fish provides highly digestible protein along with essential fatty acids, vitamins, and minerals, making it a critical component of global nutrition. However, the widening gap between fish demand and supply increases pressure on aquaculture systems, including biofloc-based production systems (Avnimelech, 1999).

iii) Technical and Management Challenges

The success of biofloc systems depends heavily on precise management of water quality, aeration, and nutrient balance. This high level of management complexity often limits adoption among small-scale farmers who lack technical expertise and resources (Ebeling et al., 2006). In addition, biofloc systems require significant initial investment for aeration equipment, monitoring tools, and infrastructure development. Although operational costs may decrease over time due to reduced feed usage, the initial capital requirement remains a major barrier (Azim & Little, 2008).

iv) Species-Specific Limitations

Biofloc technology is not universally suitable for all aquaculture species. Some species cannot effectively utilize microbial flocs as a food source and may require supplementary feeding. This limits the efficiency and applicability of BFT for certain high-value or sensitive species (Avnimelech, 2009).

Conclusion

Biofloc technology has emerged as an innovative and sustainable approach in modern aquaculture. Although biofloc technology has certain limitations, its advantages strongly outweigh the challenges. With proper design, technical support, and farmer training, biofloc technology can significantly increase aquaculture productivity while ensuring environmental sustainability. In near future, BFT is expected to play a major role in meeting the rising global demand for fish and seafood, making it a promising solution for eco-friendly and resource-efficient aquaculture development.

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