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Modern Aquaculture Techniques

Gokul S[1], Dinesh Kumar[1], Puneet Kumar Patel[1], Mari Selvam Murugan[1], Avadhutha Nikhil[1]
College of fisheries (ANDUA&T), Kumarganj, Ayodhya (U.P), India
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Abstract

Aquaculture is a fast-expanding industry that is now essential to the provision of sustainable food. Traditional aquaculture techniques do, however, confront several difficulties, such as high operating costs, water scarcity, and environmental degradation. This study examines how cutting-edge technologies like cage culture, aquaponics, Recirculating Aquaculture Systems (RAS), and Biofloc Technology (BFT) provide contemporary ways to improve fish farming's sustainability and output. Aquaculture is becoming a more eco-friendly and efficient practice thanks to integrated systems like Integrated Fish Farming (IFF) and Integrated Multi-Trophic Aquaculture (IMTA) and the Internet of Things (IoT). Together, these developments help aquaculture's future by providing creative, sustainable ways to satisfy the world's growing food needs while reducing its negative effects on the environment.

Keyword: Modern Aquaculture, Recirculating Aquaculture Systems (RAS), Biofloc Technology (BFT), Cage Culture, Aquaponics, Integrated fish farming, Integrated Multi-Tropic Aquaculture, Internet of Things and Aquamimicry.

Introduction

Fish, crustaceans, mollusks, and aquatic plants are among the aquatic animals that are cultivated under controlled conditions in aquaculture, often known as fish farming. Given its humble origins in private ponds and coastal enclosures, aquaculture currently provides more than 50% of the seafood consumed worldwide, according to the Food and Agriculture Organization (FAO). However, conventional fish farming practices have come under fire for contaminating rivers, dispersing illness, and causing overfishing (by procuring feed). The aquaculture playbook is being rewritten as a result of new, high-tech methods.

Innovative technologies that optimize resource use, improve environmental sustainability, reduce water usage, improve feed availability, and improve waste utilization—like Biofloc Technology (BFT), cage culture, aquaponics, and Recirculating Aquaculture Systems (RAS)—have significantly advanced the industry (Avnimelech, 2012; Jena *et al*., 2017). Together with strategies like Integrated Fish Farming (IFF) and Integrated Multi-Trophic Aquaculture (IMTA), these systems seek to increase productivity while reducing environmental damage and increasing profits through various cultures. In order to maintain the ideal level of water quality parameters and replicate estuarine conditions, aquamimicry is a novel new concept that involves producing blooms of zooplankton, primarily copepods, which serve as a good source of nutrition as a supplemental form for the cultured shrimps and promoting the growth of beneficial bacteria.

Biofloc Technology (BFT)

The aquaculture industry is under increasing pressure to increase output while reducing environmental effect as worries about global food security grow. In order to overcome these obstacles, Biofloc Technology (BFT) has become a ground-breaking method that converts waste into useful nutrients for aquaculture systems. First presented by Ifremer-COP (French Research Institute for Exploitation of the Sea, Oceanic Center of Pacific) in the 1970s, this ground-breaking technique has undergone substantial development over the years to become a vital component of contemporary, sustainable aquaculture methods (Avnimelech, 2012).

Working Principles

BFT's basic idea is to keep the carbon-to-nitrogen ratio between 10:1 and 20:1 at an ideal level in order to encourage the growth of helpful microorganisms that turn waste materials into premium single-cell microbial protein (Gómez-Gil *et al*., 2020). These microorganisms, which are referred to as bioflocs, are collections of bacteria, protozoa, algae, and other organic particles that are bound together by a loose mucus matrix. According to Goddek *et al*. (2015), this microbial community improves water quality, gives cultured organisms extra nourishment, and increases system biosecurity overall.

Benefit of biofloc technology

- Eco-friendly culture system.
- It reduces environmental impact.
- Judicial use of land and water.
- Limited or zero water exchange system.
- Higher productivity (It enhances survival rate, growth performance, better feed conversion in the culture system of fish).
- Higher biosecurity.
- Reduces water pollution and mitigate the risk of introduction and spread of pathogens.
- It reduces utilization of protein rich feed and cost of standard feed.
- It reduces the pressure on capture fisheries.

Cage Culture in Aquaculture

Fish raised in floating or submerged cages in man-made or natural water bodies, such as lakes, rivers, or reservoirs, are known as cage culture. These cages, which are usually constructed of mesh or netting, keep the fish contained while allowing water circulation. This method optimizes the use of existing water resources while offering a regulated environment for fish farming (Hossain *et al*., 2021; Tacon *et al*., 2020). Cage culture has several benefits, including as minimal startup costs, straightforward maintenance techniques, and harvesting simplicity. Feeding methods are simple, and effective management of water resources is made possible by resource flexibility. There are other uses for cage systems, such storing fish for sale. By employing open water enclosures, this technique has the potential to increase fish productivity and lessen reliance on land-based farms (Naylor *et al*., 2020; Sinha *et al*., 2022).

Benefit of cage culture

- Numerous water resources that would not normally be able to be harvested, such as lakes, reservoirs, ponds, strip pits, streams, and rivers, can be utilized. Consult your state's fish and wildlife agency as certain state regulations may limit the use of "public waters" for fish production.
- A relatively low initial investment is all that is required in an existing body of water.
- Harvesting is simplified.
- Observation and sampling of fish is simplified.

Aquaponics

Hydroponics and aquaculture are combined in aquaponics. According to the Food and Agriculture Organization of the United Nations (1988), aquaculture is the production of aquatic creatures such as fish, mollusks, crustaceans, and aquatic plants. With hydroponics, plants are grown without soil and nutrients are delivered by water (Diver, 2006). According to Rakocy *et al*., (2006), Endut *et al*., (2010), and Thomas *et al*., (2019), aquaponics is a symbiotic system in which fish and plants are cultivated together. The fish's waste supplies nutrients to the plants, while the plants assist purify the water, resulting in a healthy environment for the fish.

Toxic chemicals like nitrite and ammonia must be controlled in aquaculture operations since they can stress fish if left behind. The ecology will be greatly impacted by this quickly expanding industry, which is predicted to provide 54% of the 200 million tons of fish that will be required by 2030 (Food and Agriculture Organization of the United Nations, 2018). Aquaponics can be utilized successfully in controlled circumstances because it doesn't require soil, which makes it appropriate for metropolitan locations with limited land.

By using nitrifying bacteria to transform ammonia into nitrate (NO_3^-), which plants need as fertilizers, aquaponics offers a solution. This technology aids in water treatment in RAS systems and lessens the demand for additional nutrients in hydroponics. Leafy greens with low to medium nutrient requirements, such as capsicum, tomatoes, lettuce, cabbage, basil, spinach, chives, herbs, and watercress, are frequently grown in aquaponics. Even though the setup cost is significant at first, there are good returns because of the lower recurring costs. Aquaponics recycles waste and requires less water, land, and labor overall.

Working Principle of Aquaponics System

The waste-filled water is sent to a filtering system, which collects solids and encourages the growth of good bacteria. These bacteria are essential to a two-step process known as nitrification. Certain bacteria first change ammonia (NH_4) into nitrite (NO_2), which is subsequently changed into nitrate (NO_3) by further helpful bacteria. Since nitrate is a type of nitrogen that plants can readily absorb and use for growth, this conversion is crucial. Following nitrification, the aquaponics system's plants receive nutrient-rich water that has been adjusted with nitrates. The plants receive the nutrients they require to flourish from this water, which serves as a natural fertilizer. In addition to absorbing these nutrients, the plants aid in filtering the

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water, eliminating surplus nutrients and enhancing its purity. The cycle is completed by returning the clean water to the fish tank once the plants have consumed the nutrients. The foundation of an aquaponics system is the reciprocal link between fish and plants, whereby both are dependent upon one another for growth and sustainability. The plants help maintain the water clean and healthy for the fish, and the fish provide the plants nourishment.

The system is made efficient by these interrelated processes, which also produce a sustainable ecosystem that maximizes productivity and minimizes waste. Aquaponics systems may produce large quantities of fish and vegetables by utilizing the innate connections between fish and plants, providing a sustainable substitute for conventional agricultural practices. This collaboration demonstrates how aquaponics may preserve valuable natural resources while assisting in meeting the growing need for wholesome, fresh food.

Advantages of Aquaponics

Resource Efficiency: Aquaponics maximizes resource use by recycling water and nutrients within the system. It uses much less water than conventional soil-based agriculture and eliminates the need for synthetic fertilizers.

Environmental Sustainability: Aquaponics reduces the release of harmful substances into the environment. Its closed-loop system lowers the risk of water pollution, and the absence of chemical fertilizers and pesticides helps preserve ecosystems.

Increased Productivity: The mutual relationship between fish and plants enhances productivity. The nutrient-rich water promotes faster plant growth, leading to higher yields than traditional farming practices.

Year-Round Cultivation: Aquaponics allows for year-round cultivation, unaffected by seasonal changes. The controlled environments of greenhouses or indoor setups enable continuous production regardless of external conditions.

Recirculating Aquaculture System (RAS) Technology

The term "recirculating aquaculture system" (RAS) technology describes land-based closed systems that use serial reconditioning to minimize water consumption while cultivating aquatic species. By effectively reusing water, these systems improve food security and reduce environmental effects (Jena *et al*., 2017). In order to safely reuse water, RAS consists of a number of treatment procedures that efficiently eliminate organic compounds and other oxygen-demanding components from wastewater, including suspended particles, nutrients, fats, oils, and pathogens (Jena *et al*., 2017). The bulk of solid materials are first removed from wastewater by running it through mechanical filters, such as settlement tanks, sand filters, drum filters, and screen filters, which remove larger suspended particles, debris, and floating materials (including wood, paper, rags, and plastics).

Working principle of RAS

The biofilters used in recirculating aquaculture systems (RAS) treat liquid waste by passing it through a microbial film, also known as a zoological film, which is normally between 0.2 and 2.0 mm thick. Numerous microorganisms, such as bacteria, fungi, protozoa, and algae, make up this film. The film's naturally occurring microorganisms efficiently decompose organic components and purify the liquid by changing the fish's expelled ammonia (NH_4^+ and NH_3) into less toxic nitrates. Since oxygen is necessary for fish growth and food metabolism, reoxygenating the system's water is essential to reaching high output densities. Aeration and oxygenation can raise the amount of dissolved oxygen. Aeration increases the surface area available for oxygen dissolution by pumping air through an air stone to produce tiny bubbles in the water column. It is crucial to maintain the ideal pH level in RAS, which is usually achieved by adding materials like sodium hydroxide (NaOH) or lime (CaCO3). Fish may be poisoned by high levels of dissolved carbon dioxide (CO_2), which can result from a low pH. Aeration systems can also be used to degas CO_2 in order to control pH (Jena *et al*., 2017). Each species of fish has a recommended temperature range and going beyond these can have detrimental health effects or even cause death. Temperature also influences dissolved oxygen concentrations and can be regulated through submerged heaters, heat pumps, chillers, or heat exchangers (Piedrahita, 2003). Finally, before the water is reused in culture units, it is disinfected using UV radiation or ozone treatments to eliminate pathogens and ensure water quality (Chamberlain *et al*., 2021).

Benefits of RAS

- Low water requirements.
- Low land requirements.
- Water quality parameters can be easily rectified.
- Independence of adverse weather conditions.
- High stocking density of desired species and productions.
- Most efficient; feed conversion is near 1:1.
- Reduce or eliminate vaccine, antibiotic and pesticide uses.
- Consistent production.
- Eco-friendly.
- Improve health and performance of the fish species.

Integrated fish farming (IFF)

Integrated farming is the term used to describe the progressive links between two or more farming operations that are related to agriculture. one in which farming is the main element. When fish is the focal point of the system, it's known as integrated farming (Ayyappan, 2011). On the other hand, aquaculture, agriculture, and livestock are all used, managed, and produced together in integrated fish farming systems, with an emphasis on aquaculture. A sustainable farming approach that improves resource efficiency, reduces risk through crop diversity, boosts edible fish production for small-scale farming, and makes money is the integration of fish farming with agriculture and animal husbandry.

Working principle of IFF

In an integrated fish farming (IFF) system, the byproducts or wastes from one system, such as minor agricultural commodities, become inputs for fish culture systems. For example, byproducts from fodder plants, fruit plants, and agricultural crops such as rice bran, rice polish, flour, oil cake, and soybeans are processed and used as feed in aquaculture (FAO, 2018). Additionally, waste from livestock—such as urine and dung from cows, poultry, chickens, pigs, rabbits, goats, sheep, and silkworms—serves as manure to generate fish food organisms, supporting the aquatic food web (Sharma *et al*., 2019).

Agri-based and livestock-fish systems are the two primary IFF system types used in India. While paddy-fish, mushroom-fish, seri-fish, and vermicompost-fish are minor agricultural techniques, aquaculture is the main component of agri-based systems (Das *et al*., 2020). By optimizing the synergies between the components, livestock-fish systems—such as cattle-fish, pig-fish, goat or sheep-fish, duck-fish, and rabbit-fish—are intended to boost agricultural productivity (Yadav *et al*., 2021). A sustainable farming method, IFF promotes biodiversity, ecological balance, and the integration of soil and water fertility management techniques while increasing food production (FAO, 2018).

Benefits of IFF

There are many advantages to integrated fish farming. It has enormous potential to boost production and improve food security. The system diversifies farmers' sources of income while making the most use of the natural resources that are available. Additionally, it increases the fertility of soil and water, which lessens the need for chemicals like fertilizers, insecticides, and antibiotics. Integrated farming helps environmentally friendly activities by encouraging sustainable practices and the conservation of aquatic biodiversity. It also recycles trash and byproducts, uses agricultural area efficiently, and runs organically without the use of artificial fertilizers. In the end, this approach improves economic viability and lowers production costs.

Integrated Multi-Trophic Aquaculture (IMTA)

It is a technique for concurrently raising several freshwater or marine species from various trophic or nutritional levels in the same environment (Barrington *et al.*, 2009). This method makes it possible to collect and repurpose the leftover feed, waste, nutrients, and byproducts of one species for use as fertilizer, feed, or energy by other species. By doing this, IMTA improves sustainability and resource efficiency by utilizing the complementary ecological activities of different species to produce synergistic interactions.

Working principle of IMTA

In Integrated Multi-Trophic Aquaculture (IMTA), inorganic extractive species like seaweed and organic extractive species like shellfish and herbivorous fish are cultivated alongside feed species like shrimp or finfish. By encouraging improved management techniques, this method develops a sustainable, well-balanced strategy for social acceptability, economic stability through product diversification, and environmental bio mitigation. Higher trophic level carnivorous species in IMTA release particulate organic materials (such fish waste), phosphorus (orthophosphate), and soluble inorganic ammonia. Seaweeds immediately absorb these inorganic nutrients from their surroundings, whereas deposit feeders and shellfish devour organic particles (fish excrement and uneaten feed) and transform them into excretory products that seaweeds then absorb. This nutrient recycling across different trophic levels supports biodiversity, biosecurity, and ecosystem health while increasing food production in a sustainable manner.

IMTA can be summarized as: Fed Aquaculture (e.g., finfish) + Organic Extractive Aquaculture

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(e.g., shellfish) + Inorganic Extractive Aquaculture (e.g., seaweed).

Benefits of IMTA

- Integrated Multi-Trophic Aquaculture (IMTA) offers great potential for increasing food production and ensuring food security.
- It promotes both economic and environmental sustainability by converting by-products, wastes, and uneaten feed into useful resources.
- IMTA helps reduce eutrophication, supports economic diversification, and minimizes negative environmental impacts.
- This eco-friendly system efficiently utilizes all trophic levels, making it a sustainable approach to aquaculture.

Internet of Things (IoT)

The need for food is rising along with the world's population. However, agricultural land is declining as a result of causes like resource depletion and the greenhouse effect. Due to their high protein content and ease of cultivation, fish have emerged as a vital resource. Global fish consumption averaged 20.5 kg per person per year, according to the FAO's 2018 report, and is predicted to increase over the next ten years.

Aquaculture has grown rapidly as a result of declining wild fish populations brought on by overfishing, pollution, and climate change. More than half of the aquatic products produced worldwide are now sourced from aquaculture thanks to innovations like big data, AI, and the Internet of Things. To preserve water quality and fight infections, some farms, however, rely on chemicals, which can be detrimental to both human health and the environment. Aquafarms need to control water quality without using chemicals because consumers are becoming more interested in sustainable and organic products.

Aquaculture depends on the quality of the water. Fish, ecosystems, and human health can all be harmed by poor water quality. Conventional techniques for evaluating water are labor-intensive and slow. The IoT-based Smart Aquaculture System (ISAS) was created in order to solve this. Temperature, pH, dissolved oxygen, and water hardness sensors are used, and they are linked to Arduino and Raspberry Pi platforms. By sending data to the cloud, the technology enables users to keep an eye on situations and get notifications. Depending on the quality of the water, it can also automatically regulate feeders and aerators. Key benefits of the ISAS include:

- Automated operation of aerators and feeders using a fuzzy logic system.
- Remote monitoring of water quality through mobile devices.
- Real-time monitoring of key water parameters to create an optimal environment.
- A 33.3% increase in shrimp survival compared to traditional methods.

Aquamimicry System

A new aquaculture technique called aquamimicry makes it easier to introduce organic carbon without having to keep the carbon-to-nitrogen (C) ratio at a certain level. The blossoming of phytoplankton and zooplankton, particularly copepods, which provide shrimp with more food, is naturally encouraged by this system.

The Aquamimicry system's beneficial bacterial growth also improves shrimp growth performance and stabilizes water conditions (Khanjani *et al*., 2022a). By promoting the growth of advantageous microbes and plankton, such as phytoplankton and zooplankton, aquamimicry mimics the circumstances seen in natural shrimp farming. While preserving the best possible water quality, these organisms—especially copepods—can provide as an extra food source for shrimp (Romano, 2017). By simulating natural environmental conditions, the system lowers feeding costs and promotes ecological stability (Panigrahi *et al*., 2019).

Copepods and their Role

The main source of aquamimicry technology is natural goods, such copepods, which are used as live shrimp feed. This technology is known as "Copefloc." Copepods are more nutritious than rotifers and contain a lot of polyunsaturated fatty acids (PUFAs), which are essential for shrimp growth and development. These PUFAs include arachidonic acid, eicosapentaenoic acid, carotenoids, peptides, vitamins, and minerals (Satoh *et al*., 2009; Taher *et al*., 2017). Copepods have been shown to boost feed conversion efficiency, boost immunological function, and improve post-larval (PL) shrimp growth performance in shrimp nursery culture systems, particularly in Penaeus vannamei shrimp (Abbaszadeh *et al*., 2022).

Fermentation Process in Aquamimicry

In the Aquamimicry system, rice bran is fermented with probiotics and water, with hydrolyzing enzymes used for a 24-hour fermentation process. This fermentation occurs at a rate of 500 to100 kg per hectare, and within a week, the bloom of live feed, such as copepods, can be observed (Khanjani *et al*., 2022).

Advantages of the Aquamimicry System in Aquaculture

- The culture environment in Aquamimicry systems is more stable than in traditional systems, providing better environmental control (Deepak *et al*., 2020).
- It creates an unfavourable environment for harmful bacterial pathogens, and the risk of black soil formation is significantly reduced (Romano, 2017).
- Aquamimicry can increase shrimp production yield while reducing expenses, enhancing profitability. The system minimizes the production of suspended solids and waste, leading to a reduced dependency on commercial feeds. This decreases the biological oxygen demand and reduces the need for intensive aeration, optimizing energy consumption (Romano, 2017).
- Simulating natural culture conditions in the Aquamimicry system triggers better growth performance in shrimp (Romano, 2017).
- The system is relatively easy to establish and operate, requiring less technological infrastructure and knowledge. It is accessible to aquaculture farmers with lower technical expertise (Catalani, 2020).

Conclusion

The goal of this fastest-growing industry is to minimize its ecological impact while addressing the global food security concern. The traditional system has a number of issues, including However, disease outbreaks provide serious difficulties, resulting in financial losses and environmental issues. Numerous approaches have been developed to solve these issues, and integrated systems are opening the door to fish farming that is more productive and sustainable. The sector is changing as a result of innovations like Biofloc Technology (BFT), Cage culture, Integrated Fish Farming, RAS, Aquaponics, and IMTA, which enable effective resource use and less environmental impact. When taken as a whole, these developments show aquaculture's future and provide viable answers to the world's problems, ensuring both environmental sustainability and food security.

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