

Review

Biofloc Application Using Aquaponics and Vertical Aquaculture Technology in Aquaculture: Review

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Abstract: Some aspects of traditional aquaculture have negative impacts on the aquatic environment, leading to pollution and disease outbreaks in farmed organisms. Biofloc technology (BFT) is a closed aquaculture system that utilizes specific microbial communities to remove ammonia emitted from aquaculture organisms or adds carbon to the aquaculture system to improve water quality. BFT has benefits, such as increasing production and improving water quality, and reducing disease spread and pollution, without the need for water exchange. However, there are disadvantages, such as rapid changes in water quality due to accumulation of dissolved nutrients and total suspended solids (TSS) and the requirement for expensive aeration equipment to maintain dissolved oxygen. BFT can be enhanced in value and efficiency by combining it with other aquaculture technologies, such as aquaponics and vertical aquaculture to overcome the disadvantages. The integration of biofloc with technologies from the fourth industrial revolution holds potential for further development, while aquaponics and vertical farming can eliminate geographical limitations and accelerate the urbanization of aquaculture. The integration of aquaponics and vertical aquaculture with BFT has potential for development, accelerating the urbanization of aquaculture and removing geographic limitations.

Keywords: biofloc system; integration of biofloc and aquaponics; integration possibilities of biofloc and vertical aquaculture technology; sustainable aquaculture; integrated aquaculture

Key Contribution: This review discussed the positive aspects of the convergence of BFT with other aquaculture technologies (aquaponics and vertical aquaculture). In addition, the need for future aquaculture industry development through the development of an integrated aquaculture system using BFT was emphasized.



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1. Introduction

Aquaculture is the fastest-growing industry in the animal food sector, surpassing captive fishing and being recognized as an alternative, efficient and sustainable food supply [1]. In addition, the global demand for aquatic products is steadily increasing, and it is expected to accelerate even further with the growing world population [2]. However, the traditional aquaculture system faces limitations due to a vicious cycle where the high density of farms pollutes the coastal environment, which in turn contaminates the farms

themselves, leading to increased flow rates to maintain water quality and further pollution of the coastal environment [3,4]. In addition, the traditional aquaculture methods have a low water exchange rate and a limit to removing waste, which is likely to lessen the immunity of aquaculture organisms and reduce overall production through frequent disease outbreaks, resulting in increased costs [5]. Therefore, new sustainable technologies and management strategies must be introduced to address the negative aspects of traditional aquaculture [6].

BFT is gaining attention as a technology that compensates for the challenges of traditional aquaculture and offers benefits related to high production yield, feed protein recycling, water quality and bacterial infection control [7]. BFT is a closed water purification process that improves water quality by removing ammonia emitted from aquaculture organisms by using specific microbial communities, such as heterotrophic bacteria and nitrifying bacteria, or by adding extra carbon to the aquaculture system through an external carbon source or high carbon content in feed [2,8]. BFT operates by minimizing or eliminating water exchange while maintaining high stocking density through the principle of decomposing ammonia derived from feces and feed waste using bacteria [9]. In addition, effective microorganisms have a virtuous cycle structure in which they proliferate through ammonia and form biofloc through aggregation, which is used as a food source for aquaculture organisms [10]. The diverse aerobic microbial community within BFT water quality plays a major role in the nitrification process, which stabilizes water quality by converting ammonia to nitrite and nitrite to nitrates [11]. In the BFT system, ammonia–nitrogen is removed through three pathways: photoautotrophic removal by algae, autotrophic bacteria that convert ammonia–nitrogen to nitrate–nitrogen, and heterotrophic bacteria that directly convert ammonia–nitrogen to microbial biomass [12]. In particular, heterotrophic bacteria remove ammonia–nitrogen by assimilating it into microbial biomass at high carbon and nitrogen (C:N) ratios, so it is important to increase the C:N ratio by supplying additional carbon sources [12–14]. The core of BFT is to increase the metabolic ability to remove waste products, such as ammonia, by multiplying heterotrophic bacteria and microbial flocs by adding a carbon source to the breeding water, while converting them into edible biomass for aquaculture organisms [15]. Indeed, biofloc serves as a high-quality food source that can be consumed by cultured organisms, resulting in significant cost reductions in aquaculture, where feed accounts for 40–60% of operational costs [16]. In addition, the use of biofloc as a food source for aquaculture organisms can improve feed efficiency in aquaculture by reducing protein requirements for feed and improving the nitrogen utilization efficiency of aquaculture organisms [17,18]. Biofloc contains not only protein, lipid, and carbohydrate but also essential amino acids, essential fatty acids, antioxidants, and vitamins [18,19]. This provides beneficial effects related to promoting growth, enhancing immunity, improving survival rates, and enhancing reproductive performance in cultured organisms [19,20]. Furthermore, the beneficial microorganisms within the biofloc system can play a significant role in supporting the health of aquaculture organisms; they compete with pathogenic bacteria in the environment, leading to a substantial decrease in both the quantity and harmfulness of pathogenic bacteria [21,22]. BFT has the advantage of not requiring water exchange, because effective microorganisms in the water naturally purify the water quality [23]. The main advantage of BFT's zero water exchange system is enhancing biological security by preemptively blocking the introduction of pathogenic bacteria from water exchange [9,24]. Additionally, the zero water exchange system has an important meaning in environmental pollution prevention and biosecurity by effectively controlling the spread of disease to the natural aquatic environment through aquaculture wastewater [25]. Furthermore, since the zero water exchange system prevents the escape of aquaculture organisms and maintains the optimal temperature required for aquaculture with minimal energy consumption, it suggests that stable production of aquatic products is possible through BFT [26,27]. However, some disadvantages of BFT have also been reported. BFT operates as a closed aquaculture system, which has the disadvantage of water quality being susceptible to easy fluctuations [28]. Particularly, for systems dependent on sunlight, the performance of BFT can vary according to seasonal changes in daylight

duration [29]. In addition, the inconsistent nitrogen cycle and reduced activity of effective microorganisms in the water may cause water pollution due to accumulation of nitrite, ammonia and nitrate in BFT, potentially harming the health of aquaculture organisms [30]. In order to counteract the rapid decrease in dissolved oxygen caused by the excessive proliferation of beneficial microorganisms, BFT systems require the use of aeration devices to maintain high levels of dissolved oxygen, which can result in higher facility costs [31]. BFT is obviously an aquaculture technique with many advantages, but many disadvantages have also been reported. However, if BFT is combined with other aquaculture technologies to compensate for its shortcomings, it is believed that it will be recognized as having higher value as an aquaculture technology. This review expects that introducing plants that can grow by absorbing dissolved nutrients, such as nitrate and phosphorus, generated by microorganisms decomposing fish waste or feed into the biofloc system will be a way to complement the shortcomings of biofloc [32–36]. Therefore, in this study, aquaponics technology and vertical aquaculture, which are expected to have higher value when combined with BFT technology, are studied.

2. Aquaponics with BFT

Aquaponics, a term that combines ‘aquaculture’ and ‘hydroponics’, was developed in the late 1970s and early 1980s by Mark McMurtry with researchers in the New Alchemy Institute and North Carolina State University in the United States; this innovative system was named the ‘Integrated AquaVegeticulture System’ (IAVS) [37]. The historical roots of aquaponics can be traced back to ancient civilizations including the Aztec chinampas, Egypt, Babylon, and Far Eastern countries such as China and Thailand, where cultures combined fish and vegetable farming [38]. The development of the first successful commercial aquaponics system dates back to 1969, when William McLarney and Nancy and John Todd replicated the prototype of the Aztec aquaponics system [39,40]. Most of the research related to aquaponics started in the early 1970s, and modern commercial-scale aquaponics was established in 1981 by Dr. James Rakocy and his team at the University of the Virgin Islands [37,40].

Aquaponics is an integrated polytrophic system that combines elements of aquaculture with circulating aquaculture, such as BFT and recirculating aquaculture systems (RAS) [41]. Water rich in nitrogen sources, such as ammonia and nitrite, that nurture aquatic organisms are used as nutrients for plants to grow, and the water from which the nitrogen source has been removed through the plants goes back into the tank and helps the stable growth of aquatic animals (Figures 1 and 2). The interconnection between aquaculture and hydroponics can effectively solve the problems of each system, which can be used as a promising sustainable food production technique in the agricultural and fishery industry [42]. Today, commercial aquaponics production takes place in an environment that is easy to control, such as a greenhouse or an outdoor location with a good climate, using the facilities and equipment required for aquaculture and agriculture, and the application of most aquaponics focuses on aquaculture, hydroponics, engineering, microbiology and water quality [37,43]. Depending on the purpose of the aquaponics system, various sizes and designs of have been developed in many European countries, and the aquaponics technology can be an innovative alternative to solve the food and environmental problems the world is facing, and has thus become a rapidly evolving technology in recent years [44,45].

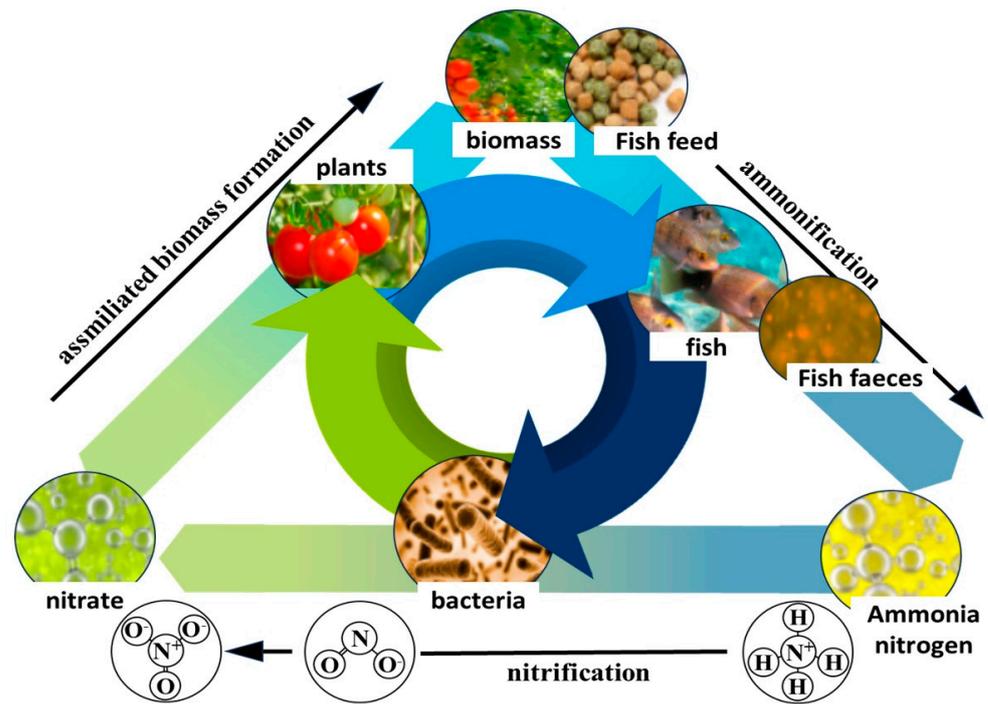


Figure 1. Symbiotic aquaponic cycle between aquatic animals and plant growth in aquaponics system (Reprinted with permission from MDPI. Copyright (2015). Simon Goddek; Source: Goddek et al. [42], <https://doi.org/10.3390/su7044199>).

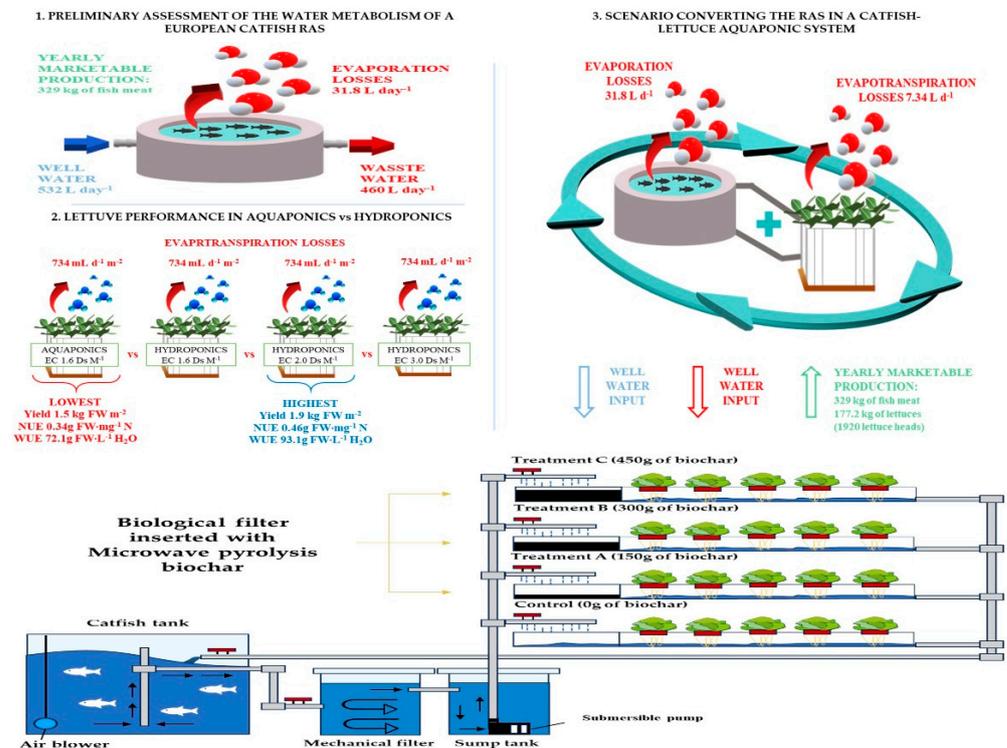


Figure 2. Aquaponics system that uses nitrates discharged from a fish breeding tank as nutrients for plants, and circulates breeding water from which the nitrogen source has been removed back to the fish tank (Reprinted from *Science of The Total Environment*, Vol 687, Calone et al. [46], p. 9, Copyright (2019); Reprinted from *Journal of Hazardous Materials*, Vol 396, Su et al. [47] p. 1, Copyright (2020), with permission from Elsevier).

Aquaponics supplies a very suitable function for urban environments, land scarce or polluted areas, and rural areas, and it will be possible to produce fresh and high-quality aquatic products and agricultural products due to its characteristics of intensive production in a small space, which also helps alleviate the urban heat island phenomenon [48]. Aquaponics is being proposed as a sustainable aquaculture concept because high yields of aquatic life and plants can be expected by diversifying food production, saving water consumption, and substantially utilizing aquaculture feed in a small space [49]. In fact, production through aquaponics has been shown to yield six times more than traditional outdoor farming and aquaculture facilities while utilizing only one-sixth of the space and water [40]. It is also possible to provide sustainable and high value-added food, including fruits, flowers and herbs, without the use of antibiotics for aquatic animals and pesticides for plants, in nearby large cities and dry areas [34]. Tokunaga et al. [50] established a combined aquaponics system of tilapia and lettuce in Honolulu, Hawaii, USA, and they reported that plants contributed 80% of the total production. Quagraine et al. [51] analyzed aquaponics farms of various scales in the Midwest of the United States, and they found that plants accounted for 80% of production, regardless of investment level and size. Various types of plants, including fruits (tomatoes, strawberry, cantaloupe watermelon, dwarf citrus tree, etc.), vegetables (lettuce, broccoli, onion, carrots, cucumbers, beans, squash, radish, peas, Swiss chard, zucchini, asparagus, beets, spinach, peppers, etc.) and herbs (basil, thyme, grafted rose, orchid, sage, tulip, parsley, lemongrass, violas, pansy, wheatgrass, cilantro, oregano, aloe vera, etc.) are grown through aquaponics systems [52]. In addition, selection of fish species with high disease resistance and environmental resistance is important in aquaponics, and species such as tilapia, carp, catfish, goldfish and largemouth bass can be utilized for the successful application of the aquaponics system [52].

Aquaponics is a system that combines two technologies, a closed circulation aquaculture systems and hydroponics (plant production from water without soil) in a closed loop system, and the most important challenge for this technology is to control the conversion of ammonia generated during the rearing process of aquatic animals to nitrate and to balance the concentration in the aquatic animal tank and plant growth layer (Figures 3–5) [48]. BFT promotes the growth of a diverse microbial community consisting of bacteria, microalgae, protozoans, and other invertebrates [53]. These communities play an important role in natural productivity, water quality and nutrient cycling, and also serve as a food source for aquaculture organisms [54]. However, BFT can lead to high nutrient content in effluents due to low water exchange and high stocking densities [34]. To address this issue, water reuse or nutrient recycling in aquaponics systems can be considered [55,56].

Additionally, aquaponics can be more efficient when there is a diverse microbial community, known as BFT [57]. A nitrogen cycle must be established for the stable operation of the aquaponics system, and ammonia released during fish breeding is converted to nitrite by ammonia oxidizing bacteria (AOB), which is then oxidized to nitrate by nitrite oxidizing bacteria (NOB, mainly *Nitrobacter* spp. and *Nitrospira* spp.) [8,58]. Nitrates generated in fish tanks act as nutrients for plants and promote growth, and effective circulation can be achieved only when there is a good balance between nitrate production by aquatic animals and plant biomass [52]. Moreover, in contrast to the traditional aquaponics system, integrated systems have the advantage of being able to meet the nutritional needs of plants without relying on chemical fertilizers because the plants are supplied with a variety of nutrients (N, P, K, S, Ca, Mg, Fe, Mn, Cu, Zn, B, Mo, Al) by utilizing the food and excrement of cultured organisms [59,60]. Tetra et al. [61] reported that plant yellowing due to lack of nutrients did not occur in the integrated system of BFT and aquaponics, suggesting that the integrated system can support the growth and survival of both cultured organisms and plants.

The integrated system with BFT and aquaponics is an environmentally-friendly method of food production due to its focus on nutrient recycling and water conservation. Pinho et al. [2] named this integrated aquaculture system 'FLOCponics' and introduced it as a new type of aquaponics system that replaced RAS with the BFT system.

This integrated system has the potential to enhance economic diversity by producing value-added plant products and mitigate the accumulation of nitrate and phosphorus in the management of the BFT system [35]. The integrated system of BFT and aquaponics maintains low nitrate levels through continuous absorption by plants, as well as keeping phosphate levels either unchanged or within the recommended range for plant growth. Saseendran et al. [35] employed an integrated system of biofloc and aquaponics, using bell pepper, *Capsicum annum* L. and GIFT tilapia. Under the condition of 150 fish/m², the nitrate level in this system was 2.86 ± 0.51 mg/L, while the only aquaponics system had a nitrate level of 5.26 ± 0.49 mg/L. This significant difference was attributed to the enhanced nitrate absorption by plants in the integrated system. However, under the same conditions, there was no significant difference in phosphate levels between the integrated system and the standalone aquaponics systems. Pinheiro et al. [33] employed an integrated system of biofloc and aquaponics, using halophytes, *Sarcocornia ambigua*, and shrimp, *Litopenaeus vannamei*. The presence of plants did not result in significant differences in nitrate levels, but the nitrate levels were consistently low. Furthermore, there were no significant differences in orthophosphate levels. Pinho et al. [34] employed an integrated system of biofloc and aquaponics, using seedlings of red lettuce, butter lettuce, and crispy lettuce as the plants, and Nile tilapia as the fish, *Oreochromis niloticus*. This integrated system maintained low levels of nitrogen compounds (ammonium nitrogen, nitrite, and nitrate), with concentrations of 1.5, 0.0, and 0.1 mg/L, respectively, as a result of plant absorption. However, orthophosphate levels were observed to be at 20.6 mg/L, but still within the recommended values for leafy vegetables. Several studies have shown the sustainability of the integrated system by maintaining the aquaculture environment rather than promoting the growth performance of animals and plants. For instance, this system showed that water quality parameters, such as dissolved oxygen, temperature, pH, and salinity, remained within the appropriate environment for Nile tilapia (*Oreochromis niloticus*) and shrimp (*L. vannamei*) [1]. Furthermore, the aquaponics system regulates the levels of TSS, which accumulate due to organic waste, by utilizing them to promote the growth of plants [62]. The halophyte plant (*S. ambigua*) in the integrated system effectively reduced the nitrate level and TSS, while promoting microbial growth through root exudation and biofilm formation [1]. The appropriate consumption of nitrogen and phosphate compounds by *S. ambigua*, was confirmed at a salinity range of 16 to 24 psu. It was also observed that this system had no adverse effects on the performance of *L. vannamei*, including survival, feed conversion ratio, and productivity [63]. The integrated system of aquaponics and BFT provided appropriate aquaculture environment for *O. niloticus* and shrimp (*Macrobrachium rosenbergii*) without adverse impacts. In this system, vegetables such as curly lettuce (*Lactuca sativa*) and watercress (*Rorippa nasturtium-aquaticum*) played a crucial role in regulating nitrate levels produced by chemoautotrophic bacteria [64].

The research on an integrated system of BFT and aquaponics is currently in its initial phase with a limited number of published papers and a lack of standardization in system design and experimental methodologies. Several factors need to be considered for the sustainability and optimization of this system. In marine aquaculture and hydroponics, the use of salt-tolerant or halophyte plants is essential [65]. It is necessary to consider the appropriate salinity for ideal growth, as the degree of salt tolerance varies among different plant species [63]. The yield of aquatic organisms and plants is affected by the water quality of the integrated system. Water quality indicators, such as dissolved oxygen, turbidity, nitrate, phosphate, calcium and potassium, depend on the stocking density of fish and plants, which can affect their growth performance [1,35]. For example, when the amount of nutrients required for plant growth is exceeded, the absorption of nitrate can be stopped, leading to an increase in nitrate concentration in the water [62]. In addition, changes in the water quality environment can induce oxidative stress in fish and plants, thereby changing their metabolic activities and inhibiting their growth performance [1,35]. Most studies have used Nile tilapia and whiteleg shrimp, which are relatively tolerant to high concentrations of suspended solids and nitrogen compounds, while studies on other species with high

market value are limited [2]. In addition, biofloc present in the roots interferes with the plant's absorption of nutrients, which may inhibit plant growth or even cause the plant to weaken or die [2]. Therefore, applying decoupled aquaponics systems (DAPS) to BFT, which are more convenient for nutrient concentration control and solids management by separating plant and fish production units, is proposed as a promising alternative [66,67]. In conclusion, the integration of BFT and aquaponics offers an environmentally-friendly approach to food production, but further research and standardization are necessary to fully explore the potential and optimize the sustainability of this system.

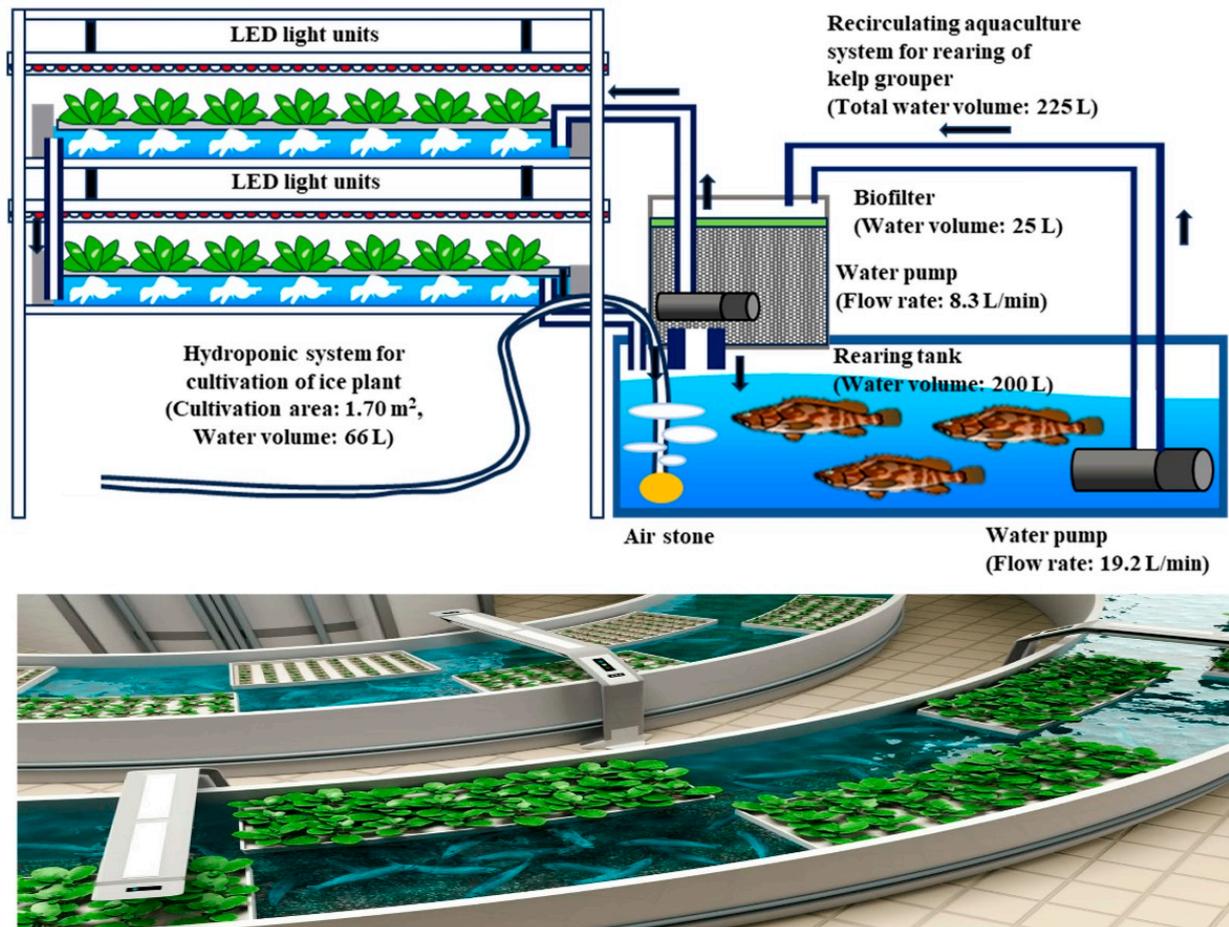


Figure 3. Example of a breeding tank system and application tank that raises fish and plants together using aquaponics (Reprinted from Elsevier Books, Endo, M. [68], p. 14, Copyright (2019), with permission from Elsevier; Source: Danish et al. [69], <https://doi.org/10.3390/su13169313>).

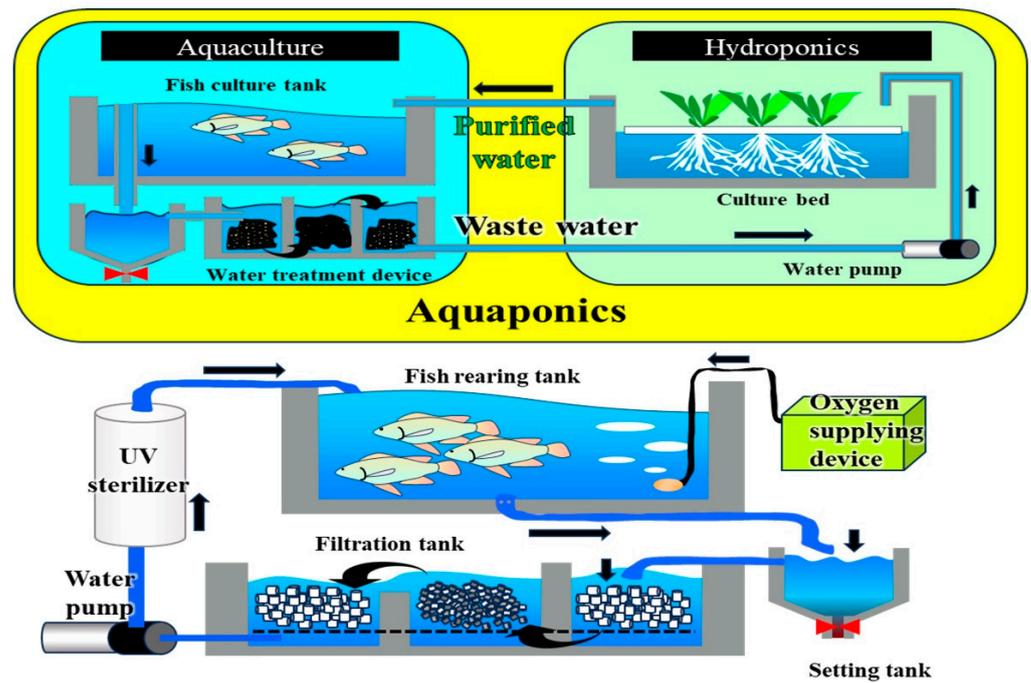


Figure 4. Schematic diagram of the process of treating water discharged from the fish tank and circulating it back into the fish tank in the aquaponics system (Reprinted from Elsevier Books, Endo, M. [68], p. 14, Copyright (2019), with permission from Elsevier).



Figure 5. Plant cultivation system of Nakdonggang National Institute of Biological Resources, Republic of Korea (A,B), and Aquaponics systems of Inland Fisheries Research Institute (National Institute of Fisheries Science), Republic of Korea (C,D).

3. Vertical Aquaculture Technology with BFT

Vertical aquaculture is an innovative system developed by Columbia University Professor Dickson Despomeer in 1999 to solve the problem of shortage of food and agricultural land, which utilizes land vertically; it is possible to produce many aquatic animals in a limited space by using the space vertically (Figure 6) [70,71]. Vertical aquaculture can be operated in multiple stages using shallow raceway systems (SRS), and SRS has characteristics such as (1) operating at low water levels ranging from 0.7 to 25 cm, depending on the size of the fish, (2) made of high density using 200–300% of the available bottom area and (3) characterized by the presence of turbulent and plug flow patterns [72]. Vertical aquaculture can be defined as artificially creating optimal environmental and economic conditions in urban buildings, which are consumption areas, for social and economic benefits, and cultivating aquatic life using aquaculture water recycling and aquaculture automation systems; in addition, the vertical aquaculture industry is a complex industry that cultivates aquatic animals in a building farm, processes and sells them, and pursues leisure tourism and commercial profits using aquaculture buildings [73]. Vertical aquafarms are being developed in various shapes and sizes from a simple two-story to a few stories high (Norway four floor vertical breeding tank, Portugal five floor vertical breeding tank, Spain six floor vertical water tank, Netherlands seven floor vertical water tank) [74]. The need to develop vertical aquaculture is being strengthened due to (1) global response to climate change, (2) the rise of aquaculture as a future life industry, (3) marine aquaculture environmental pollution and limitations in suitable sites, (4) provision of high-cost and low-efficiency land aquaculture alternatives, and (5) conversion to low-carbon, environmentally-friendly aquaculture [75].

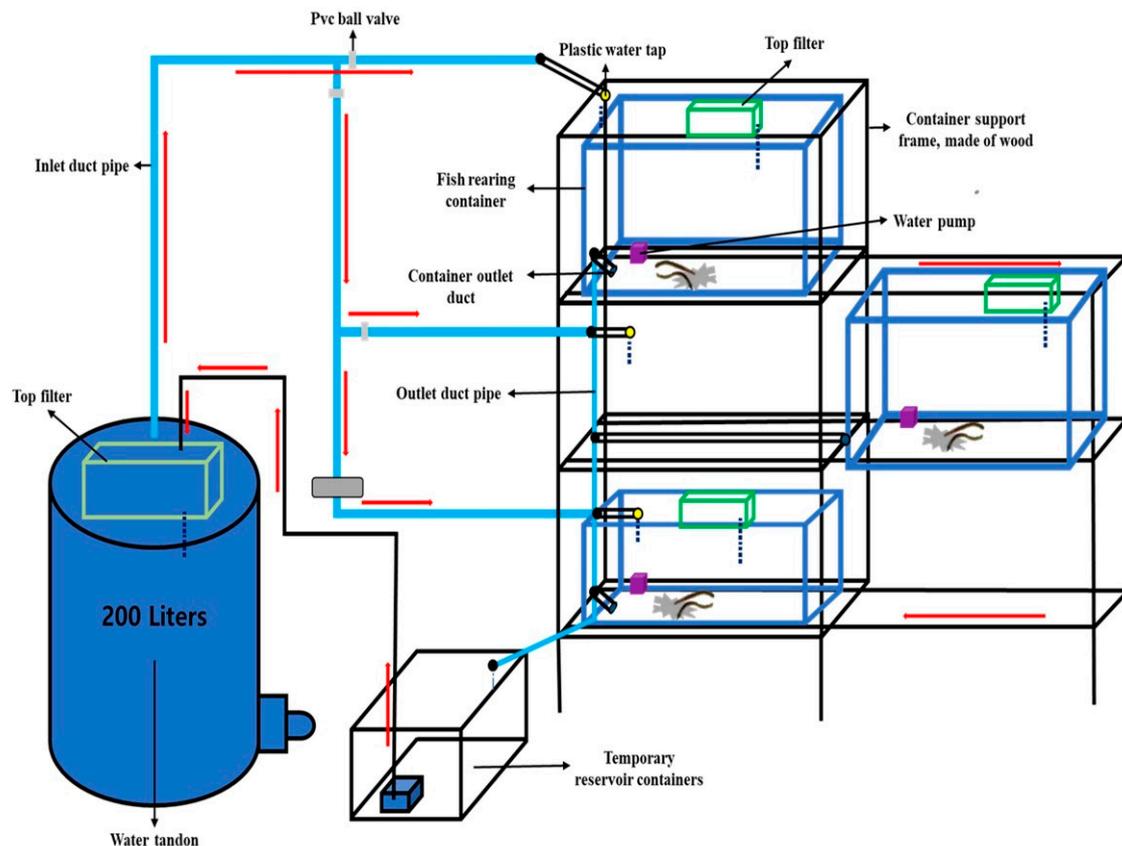


Figure 6. Experimental set up, vertical aquaculture systems (the container can be stretched horizontally to the front; the red arrows: water flows) (Reprinted with permission from Nature. Copyright (2021). Eko Harianto; Source: Harianto et al. [70], <https://doi.org/10.1038/s41598-021-90912-1>).

In applying the vertical structure, various considerations such as humidity control, natural ventilation, building envelope materials, energy efficiency, water heating, space heating and lighting requirements, should be considered along with the combination with natural hydroponic systems, aquaponics systems and biofloc systems for nutrient circulation through closed systems [74,76]. As a process of water circulation within a building, part of the circulating water is absorbed by plants or discharged out of the building as wastewater due to the metabolic activities of aquaculture organisms, and the remaining water is recirculated around the building by a system responsible for water recycling [77]. Furthermore, by filtering rainwater collected on the rooftop of the building or single-use water, such as from showers or handwashing, it is possible to increase the rate of water reuse [77,78]. Vertical aquaculture has many advantages in raising organisms. It has an advantage over aquaculture in that it is easy to maintain the temperature of the breeding water through LEDs and heating and cooling systems in a closed space; in addition, it is advantageous for plant growth through appropriate photoperiod and spectrum settings using LEDs [77,79].

Vertical aquaculture shows many differences from traditional aquaculture in various aspects, such as aquaculture location, aquaculture method and business type. Vertical aquaculture creates an artificial aquaculture environment of a double-story shelf type in a high-rise building in the city, while conventional aquaculture is carried out at sea level and at inland water level. Vertical aquaculture has the characteristics of (1) saving space for producing aquatic organisms, (2) efficiently producing aquatic products using this technology, and (3) completely controlling the environment for aquaculture production, and it is therefore ideal for construction in urban areas where space can be an issue [80]. Additionally, vertical aquaculture has the potential to play a key role in local food production because by locating a grocery store or restaurant on the ground floor of a building, fresh, inexpensive produce can be provided directly to customers without the need for distribution [78,81]. Vertical aquaculture has a very short distance from the consumption area, and it has a very high possibility of automation and technology convergence, including cooperating with mobile applications and image processing to control the module remotely with mobile application software, which can also be expanded into various business types, such as aquaculture product sales, processing and leisure tourism, as well as aquaculture [73]. Recently, research has been reported on the development of an intelligent system that can control environmental factors within the vertical aquaculture system, and efforts are being made to increase aquaculture production through the integration of the vertical aquaculture system and other technologies [82]. However, the vertical aquaculture system requires a high-cost waste management system to remove waste generated from aquaculture organisms or convert it into beneficial resources, such as liquid fertilizers or biofuels [83]. In addition, when installing a vertical farm, the waste management system has the disadvantage of taking up a lot of space because it requires about two floors in the building [77]. Therefore, vertical aquaculture technology, which has potential through its various advantages, needs to be integrated with the biofloc system, which can actively manage waste by using effective microorganisms to decompose fish waste without the need for separate facilities. The integration of the two aquaculture technologies is expected to develop into a sustainable and efficient aquaculture technology by complementing each other's shortcomings. However, there is no research on the integrated system of biofloc and vertical aquaculture technology. Therefore, it is necessary to establish indicators for the applicable biological range and limitations through standardized integrated system design and biological application research, and to evaluate the effectiveness of this integrated system through research on changes in aquaculture organisms through system application.

4. Conclusions and Future Direction

Traditional aquaculture, characterized by high-density aquaculture, leads to coastal environmental pollution, resulting in deteriorating farm health and reduced production. BFT is attracting attention as an aquaculture technology that can solve the problems of

traditional aquaculture. BFT is a closed water purification process that effectively manages water quality, controls pathogen infection, and promotes high production yield through a zero water exchange system. BFT not only reduces operating costs, but also improves the overall health and growth of aquatic organisms. However, BFT faces challenges such as vulnerability to water quality fluctuations, changing seasons, and the need for aeration to maintain oxygen levels. In order to overcome the disadvantages of BFT, development through a combination with other aquaculture technologies, such as aquaponics and vertical aquaculture, is needed. Aquaponics is a technology that combines two technologies, a closed circulation aquaculture system and hydroponics, into a closed loop system. Vertical aquaculture utilizes the vertical space of a high-rise building to efficiently produce aquatic organisms while controlling the environment. Aquaponics and vertical aquaculture are advantageous for urban environments due to their space efficiency and potential to mitigate environmental problems. Furthermore, it is expected that when these two technologies are combined with BFT, they will be able to compensate for the shortcomings of BFT. The fusion of BFT with aquaponics and vertical aquaculture is expected to provide innovative solutions to the challenges facing the aquaculture industry. These integrated systems not only enhance efficiency and sustainability of aquaculture but also have the potential to reshape the way we produce and consume aquatic products in urban environments. The development of these innovative aquaculture technologies is predicted to play an important role in a world that needs more food in the future. The development of sustainable and safe aquaculture systems will play a crucial role in supporting the food supply of rapidly growing populations. Therefore, continuous research and standardization efforts on integrated systems using BFT are essential for the future aquaculture industry.

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