Controlling pollution from floating cage culture in reservoir and lake using SMART-FCC system

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Abstract. Floating net cages culture (FCC) activity is growing rapidly and becoming one of the largest national freshwater fish producers. Most of the lake/reservoir in Indonesia has been utilized for aquaculture in the FCC system. The positive impact of the FCC includes opening up employment opportunities and increasing the income of farmers and labourers leading to the economic improvement of local community. However, there are negative impacts caused by uneaten feed such as water quality degradation, blooming of macrophytes and algae, hydropower turbine damage due to corrosion, a decreased in the abundance of fish species and others. For this reason, environmentally friendly FCC might offer a solution to control or reduce the release of uneaten feed. One of these technologies is SMART FCC that integrates fish culture and hydroponic or called aquaponics systems applied in open waters of reservoirs/lakes. The main advantage of SMART FCC is its ability to reduce FCC waste because the uneaten feed is not dispersed into the waters, rather it is collected and settles in SMART FCC. The deposited wasted feed can be used as liquid organic fertilizer for the hydroponic plants. At the end, the fish farmers get not only harvested fish but also gain additional benefits and profits from organic plant production.

Keywords: uneaten feed, pollution, aquaponics, water quality, SMART FCC

1. Introduction

Aquaculture is the biggest contributor of fish production in Indonesia. In 2017, aquaculture production contributed 16,114,991 tons or around 69.5% of the national fishery production. The production of freshwater aquaculture reached 3,457,794 tons or about 54% of the Indonesia’s aquaculture production [1]. Fish farming activities are very important in fulfilling national fish demand. This is one of the reasons that fish farming activities is a business target for fisheries entrepreneurs. Aquaculture activities in Indonesia are carried out in estuary, lakes, reservoirs, rivers swamps and ponds. Forms of cultivation activities include floating net cages, pen culture, land ponds, ponds and others. Aquaculture activities in reservoirs and lakes that are currently growing rapidly are floating net cages culture (FCC). The FCC system primarily used rectangular or elliptical stockade cages submerged partially underwater to culture [2].

Aquaculture activities with the FCC system have positive and negative impacts. One of its positive impacts is an increase in fish production and employment which can indirectly increase the household income, especially owner and labourer. The case in Cirata Reservoir shows that aquaculture using FCC has employed 6,609 laborers every 3 months or equal to 297 labourers per ha [3, 4]. The negative
impact of FCC is the degradation of water quality due to excessive nutrient input from uneaten feed released from the system. The uneaten feed is a source of organic matter. The organic matter will decompose into nitrogen, phosphorus, sulphide, carbon which will affect water quality.

Cultivation activities in the FCC require a clean water environment so that fish can grow optimally. An innovation in aquaculture technology that is able to control the pollutant input into the environment (low waste) is needed, so that the preservation of the water environment is maintained. FCC uses a Water Management System with Recirculation and Plants/Sistem Manajemen Air dengan Resirkulasi dan Tanaman (SMART) which is one of the most environmentally friendly fish culture technology solutions. SMART FCC combines fish farming and farming activities or aquaponic systems carried out in open water. SMART FCC adopts the principle of the yumina system which is an aquaponic system developed in Indonesia by integrating a fish and vegetable culture system [5] but will be applied in reservoir and lake with some modifications. This paper aims to provide an overview of the fish culture system in the FCC which is environmentally friendly.

2. Floating Nets Cages Culture System

The principle of fish cultivation using FCC is to raising the fish by confining fish with certain materials that can hold fish in it and make sure the water circulation occurs continuously. Aquaculture based on FCC system can be classified into 3 categories according to feed sources, i.e.:

1) Extensive system, which is aquaculture system where the sources of fish feed comes only from natural food such as plankton, detritus and seston. This system can be carried out in 2 types of aquatic environments namely i) lakes and reservoirs that have high productivity and ii) water bodies that accept livestock or domestic waste.

2) Semi-intensive system, where the sources of fish feed containing low protein feed (<10%) usually comes from agricultural products and plants that supplement fish feed. This system can only be carried out in mainland. The source of feed comes from plants such as bran, wheat waste and household waste.

3) Intensive system, where the aquaculture system exclusively uses high protein feed (> 20%) [6]. According to Schmittou [7], the aquaculture-based FCC is an intensive cultivation system with high stocking density, yield and efficiency.

Aquaculture using FCC has several advantages including being able to be carried out in various types of water bodies both in the inland and inshore. In Indonesia, water bodies that are often used for fish farming using FCC are inland waters such as reservoirs and lakes such as in the Djuanda Reservoir, Cirata Reservoir, Saguling Reservoir, Gajah Mungkur Reservoir, Kedungombo Reservoir, Lake Toba, Lake Maninjau, Lake Limboto, Lake Tondano, Lake Singkarak, Koto Panjang Reservoir and the others. In FCC system, easy to monitoring and harvesting. FCC construction in Indonesia generally using materials that are easily found such as bamboo or wood and has simple construction [2, 6, 8].

In aquaculture system, besides having advantages, of course it also has disadvantages. The disadvantages of using FCC, among others, to reach optimal fish growth, it requires feed with complete nutrition which is quite expensive. In a water body there is a certain period of time there are symptoms of decreased oxygen (LODOS) resulting in fish experiencing gasping, aeration is needed to overcome this which is needed additional equipment. The spread of disease is easier and faster. FCC also disrupt the transportation access and navigation and increasing the rate of sedimentation. The fish cultivated in FCC are important and economically valuable fish in general, potentially changes the community structure of aquatic flora and fauna, also changes in behaviour and distribution of wild fish communities. Remaining feed that is not eaten by fish has the potential to accelerate the eutrophication in water bodies [6, 8, 9].

3. Development of FCC system in Reservoir/Lake

In 1974, FCC activities in the Djuanda Reservoir, West Java were started for the first time and by 1988 there were 15 units with 15.9 tons of productions [10]. The growth in numbers of FCC in Indonesia in several reservoirs is presented in Figure 1.
Ecological intensification: A new paragon for sustainable aquaculture

Figure 1. Growth up of FCC in several reservoirs in Indonesian

Figure 1 shows an increase trend of number of FCC in these reservoirs which is expected considering. Aquaculture business using FCC is profitable and market demand of fish product is always increasing.

To maintain the reservoir and lake ecosystem, the number of operating FCC has to be well within the carrying capacity of the reservoir/lake. For this reason, any local government that has a reservoir/lake used for FCC within their administrative area should regulates the maximum number of FCC operating in the water bodies. In 2019, the Governor of West Java has issued decision No. 660.31/Kep.923.DKP/2019 about the number of FCC in Saguling, Cirata and Ir. H. Djuanda Reservoir in accordance with for carrying capacity is 7204 for Cirata Reservoir, 3282 for Saguling Reservoir and 11306 for Ir. H Djuanda Reservoir. However, the Ir. H Djuanda and Cirata Reservoir have FCC number exceeding what has been determined by the government (Figure 1).

4. Problems of FCC in water quality

The growing business of aquaculture using FCC system in reservoir or lake has an impact on water quality. Fish feed contains about 24 - 30% protein (25.25%); 5-8% fat (5.33%); crude fiber 5-8% (6.67%); ash 5-13% (11.89%); water content of 11-13% (12%) and phosphorus 1.27 - 1.66% (1.50%) [11]. Some will be wasted in the aquatic environment which will have an impact on the waters [12]. Illustration of the amount of nitrogen (N) wasted in the waters as Figure 2.

Figure 2. Illustration of nitrogen balances for 1 ton Nile aquaculture in intensive FCC [6].
Based on the illustration in Figure 2 shows that around 20% N is wasted into the waters from uneaten feed. On the digestible feed, only about 29.3% is absorbed in the body and the rest is discharged in the form of urine, around 52.7% and faeces around 18%. This shows that more nitrogen is being wasted in the water than is retained in the fish's body.

In aquaculture activities, carbon, nitrogen and phosphorus are released. Dissolved inorganic material from nitrogen (such as NH₃) and phosphorus (such as PO₄³⁻) is released by excretion and inorganic C is released by respiration. Large faecal particles and fast wasted food will be deposited in the bottom sediments while small particles will be in the form of a suspension that will be utilized by zooplankton with its filter system and fish in the water column [13]. Some impacts arising from uncontrolled of FCC system in waters include:

1) A decrease in water quality such as a decrease in dissolved oxygen and an increase in ammonia, nitrite, sulphide and turbidity. According Guo et al. [14], waste from FCC activities, especially uneaten feed, feces, urine released directly into the aquatic environment can cause environmental problems such as eutrophication, stunted fish growth and changes in the structure of benthic communities.

2) Increased of organic matter pollution come from uneaten feed, feces and fish urine. The current condition of Ir. H. Djuanda Reservoir shows that there is a large amount of organic material deposited on the reservoir bed due to years of FCC activity which is exceeding the reservoir's carrying capacity [15, 16]. There is even a tendency of a decreasing dissolved oxygen level following the increase of organic matter concentrations in the Djuanda Reservoir [15]. The results of Krismono & Krismono's research showed that the thickness of the organic enriched in the Djuanda Reservoir at the cultivation site was 10 cm thicker than the location without FCC activities [17]. In Ir. H. Djuanda reservoir, sedimentation rate in FCC area were 35.04 – 155.84 cm³/m²/day and non FCC area were 3.28 – 47.19 cm³/m²/day. Phosphorus, nitrogen and total organic matter content in sediment from FCC area were 0.02 – 0.021; 0.5 – 0.7% and 3.35 – 4.43 respectively [18].

3) Increased nutrients, especially Nitrogen (N) and Phosphorus (P), which came from the decomposition of deposited uneaten feed from FCC at the bottom of the waters [16]. The results of the study at Lake Maninjau showed that concentrations of N-NH₄, N-NO₂ and P-PO₄ were higher in FCC area than the other areas [19].

In some reservoirs and lakes that are used for FCC activities often occur mass death of fishes which causes economic loss to farmers. This event is called upwelling or turn over. Fishes deaths generally occur in the transitional season, specifically in the end of the dry season and in the beginning of the rainy season where sudden temperature changes often occur, gale that cause water turbulence and rainy for days there is no sunlight, so there is no oxygen production from photosynthesis. Usually at the beginning of the rainy season there is a change in the surface temperature of waters that become colder and stimulate the occurrence of turbulence of reservoir or lake waters. The accumulation of uneaten feed and metabolic waste in the bottom that causes the bottom of the water becomes anoxic so that it stimulates the anaerobic process that produces toxic compounds such as ammonia, nitrite and sulphide. When this water column is stirred, anoxic conditions containing toxic compounds are raised above the water surface. Moreover, if there is a wind that blows and causes water upheaval the stirring event is very likely to occur. The mass of water that is stirred up is contain waste / poisons and low oxygen content [20, 21] as a result can cause death, especially fish in FCC.

5. Fish culture technology with SMART FCC
Based on the impact of aquaculture activities, so efforts are made to create an environmentally friendly aquaculture system design. One of them is the FCC SMART system or FCC Water Management System with Recirculation and Plants. Aquaculture system by SMART FCC can reduce the input of organic pollutants derived from uneaten feed and fish excretion. The SMART FCC system adopts an aquaponics system that is modified and can applied in open water. Aquaponics is the concept of developing a bio-integrated farming system, which is a series of technologies that combine techniques of aquaculture and agriculture. Aquaponics technology is designed to utilize water that contains
uneaten feed and feces from fish as a source of plant nutrition or in other words is a recirculating aquaculture system [22-24]. In aquaponics system, the waste produced by farmed fish supplies nutrient for plant grown hydroponically which in turn purify the water [25]. The aquaponics system is able to reduce ammonia by absorbing water from aquaculture activities by plant roots [26].

The estimation of uneaten feed that is not consumed and wasted in the waters ranges from 20% - 30% [27-29]. If it is assumed that in one cycle of cultivation requires 2 tons of feed means that there are about 400 - 600 kg of feed that is not consumed and eventually thrown into the waters. Some of the remaining feed will be deposited at the bottom and some will be dispersed into all waters and then deposited in other areas. The remaining deposited feed become resuspend particles and return to the water column. Resuspension can result in increased turbidity. Resuspension is influenced by wind and waves such as wind speed, duration and direction, water depth, water circulation patterns, level of hardness and sediment density and roughness of basic sediments [30].

SMART FCC construction is designed in such a way that it can minimize the amount of feed that is wasted directly into the waters. The construction consists of four components, namely:

1) FCC made of waterproof and more conical at the bottom of the pool. The aim is to facilitate suctioning the remaining food collected at the bottom of the pond. On each side of the pool, a circulation hole is made which aims to circulate water and air.

2) The uneaten feed suction pump is connected to the suction pipe and conduit pipe to the tank

3) Tank for uneaten feed pumping results. That is equipped with a filter from mosquito nets as a filter to separate fine and coarse particles.

4) Hydroponic construction, namely plants and growing media. This is as a phytoremediation system because it is able to absorb phosphorus and nitrogen and is used as nutrients. Whereas plant roots function as sediment traps which are able to become sediment traps from uneaten feed particles. Hydroponic growing media in the form of charcoal and husk. Plant for aquaponic is vegetable and it function as phytoremediator. Charcoal and husk are physical filters that are able to absorb organic matter [31].

Advantages of SMART FCC include:

1) Reduce loading of organic matter pollution from FCC.
2) Technology of integrated fish – vegetable production in semi closed recirculation system is food productions system which is sustainability and environmental friendly [32].
3) Minimizing the spread of uneaten feed that is wasted because it will be deposited into the bottom of the pond and become a source of nutrition for plants. The percentage reduction in P-PO₄ in the SMART FCC aquaponics system with water spinach aquaponics plants ranged from 6.3 to 84.8%. Percentage reduction of N-NO₃ and organic matter after water spinach aquaponics were 4 - 77.7% and 8.8 - 90.7%, respectively [4]. Aquaponics system can improve water quality especially ammonia concentrations [20].
4) Utilization of waste FCC as fertilizer so that decrease cost of vegetable production.
5) Producing high-value organic plant products.
6) Prevent and control of eutrophication level.
6. Conclusion
Aquaculture activities with floating net cage culture (FCC) system have positive and negative impacts. Positive impacts include increasing household income and employment. The negative impact is the degradation of water quality due uneaten feed was dispersed into waters. One of the aquaculture technologies by FCC that is environmentally friendly is SMART FCC. In SMART FCC uses the construction of waterproof ponds combined with hydroponics or called aquaponic activities that are applied in open water. Uneaten feed and fish feces will be deposited at the bottom and then is syphoned to distributed into hydroponic plants so that the hydroponic plants as phytoremediation. Observations show that SMART FCC is able to reduce phosphate, nitrate and organic matter. The advantages of SMART FCC include reduce of organic pollution loading, producing organic plants and preventing and controlling eutrophication.

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