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Review article

Review on needs assessment, design and establishment of self-sustaining fish farms

Ndatimana, G[1]., Tolulope, A.P[1]., Sulieman, M. A[1]., Abdulazeez, A[1]. and Bilyaminu, Y[1].

[1]Applied hydrobiology unit, Department of Animal biology, Federal University of Technology, Minna, Nigeria

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SUMMARY

Across the world, aquaculture has been expressing significance influence on the sustainable health of community through nutrition, livelihood improvement and countries development. This triggered ichthyologist and other researchers to develop possible way of making aquaculture accessible and sustainable. Of various models and techniques for making aquaculture efficient; there is self-sustaining fish farm through integrated system. Therefore, the present review discussed various opinion from studies performed around various geographic areas about need assessment, design and establishment of sustainable fish farms. The required needs, possible design of structure and measures to consider and operational activities to make sure that the system is being more productive, have been discussed in this review. Furthermore, this review provided comparison of aquaculture in different countries of Africa where by Egypt, Uganda and Nigeria comes to the three top of fish producers in Africa respectively. Moreover, it is anticipated that this review will provide insights to the fish farmers, researchers, ichthyologist and policy makers on the possibilities of establishing reliable self-sustaining fish farm.

Key words: Fish farming, pond, aquaculture, feed mill and self-sustaining

Corresponding author's email: **tolulopepaulade360@gmail.com**

INTRODUCTION

Globally, aquaculture played a crucial role in satisfying the community needs and also provide the easy way of addressing the issue of malnutrition, income generation and contributes to the household and countries economy in Africa (Brummett, 2008; Vagh *et al*., 2021). In fact, aquaculture also known as fish farming, involves raising fish commercially in tanks or enclosures usually for food (Joël *et al*., 2019). Fish provide the main source of animal protein to about one billion people globally and this is key to food security *(*Vagh *et al.*, 2021). About 38 million people worldwide are employed in fisheries and aquaculture, 95% of them in developing countries (Brummett, 2008). Also related industries such as processing and marketing provide employment for approximately 50 million people (Brummett, 2008). Fisheries provide an important contribution to household cash income, which also gives access to other benefits such as education, health services, clothing, other foodstuffs and hence reduce poverty (Food and Agriculture Organization, 2017). A large portion of fish production is destined for export, 40 percent of global production being traded internationally, and exports from developing countries accounting for 60 percent. They are now net exporters of fish to developed countries, having shifted dramatically from being net importers (over 1.2 million metric tons in 1985) over the past two decades (Finegold, 2009).

Therefore, as the response to the increase in demand for fish and fish products and widespread overfishing of wild fisheries (Brummett, 2008; Olopade et al., 2017) various technology have been adopted with the aim of increasing productivity in aquaculture sector (Aich *et a*l., 2020; Mohammadpour *et al.*, 2021). Thus, many studies have investigated the possible ways of boosting potential productivity of fish through various approaches (Brummett, 2008; Adeleke *et al*., 2020). By that, it was undoubtedly found that the establishment of a self - sustaining fish farm is very crucial in fish production. Consequently, that was the origin of 'Integrated Fish Farming', which is a process of farming where fish is produced in combination with other farm products and livestock, centered on or around the fish farm (Bekibele & Onunkwo, 2007; Sahoo & Yadav, 2013) . The system links each of the involved sub-systems in it, such as fish, crops, and livestock, in such a way that the waste or by-product from one sub-system can be used as an input for the next system. An integrated agriculture system can ensure the maximum utilization of all resources, such as land, water and feed, and also minimizes waste (Sahoo & Yadav, 2013).

1. Overview of aquaculture in Africa

Existence of aquaculture in Africa started in the turn of 20th century under the influence of colonization (Hecht, 2006). That is where the governments started the journey of investing and facilitate the fish farming processing (Hecht, 2006; FAO, 2010). There are various ways that have been applied for fish farming in Africa and become adopted by both farmers and the environment. subsequently, this provided successful achievements and later adopted by different countries in Africa, to the level that some of them rely heavily on aquaculture in their economy (Ozigbo, 2014; Adeleke *et al*., 2020). Evidently, the techniques that are currently applied in aquaculture were previously started in Kenya, and nowadays, Egypt, Nigeria and Uganda are the top producers of fish in Africa (Olopade *et al*., 2017)). Adeleke *et al*., (2020) made review and comparison regarding the development of aquaculture among the producers of aquaculture in Africa taking range of years from 1998 to 2018. The leading producers, Egypt, Nigeria and

Uganda, account for about 90% of total aquaculture production from the region. They revealed that, the aquaculture industry in Egypt was strengthened by rapid development from 1998 due to the consistent and cumulative interventions by the Egyptian government over the past years, as well as growing private sector driven investment. This boosted the harvest from 139,389 tons in 1998 to 1,561,457 tons in 2018., representing 71% of total aquaculture production in Africa. Those information were emphasized by (FAO, 2017) where contribution of aquaculture took important place in livelihood of the country. In Uganda, the issue of malnutrition and food insecurity, raised awareness on aquaculture for the better way to have access to protein. Furthermore, the unemployment rate played part to Ugandan aquaculture through commitment. As a result, aquaculture development received a boost through strategic interventions from the government and aids from developmental partners (Adeleke *et al*., 2020). In Nigeria, there are different aquaculture production models that are mostly backyards or cottage, integrated fish farming, table fish production, hatcheries and table fish production (Anetekhai, 2013 ; Adeleke *et al*., 2020). As country with high fish consumers (Adisa *et al*., 2021), Nigerian community tend to invest in fish farming, the factor that boost new technologies applied in aquacultural sector (Saviour, 2021). Moreover, as the country whose diverse fish rearing opportunities on either coastal area specifically for sea food and inland for conventional fish farming, it is an added advantage that eventually contribute to the economy of the country (Moruf, 2020).

3. Requirements for Self-Sustaining Fish farm

For establishing successful self-sustaining fish farm, there are essential requirements, to be considered. This includes the following: production system based on rearing facilities, type of fish cultured and cultivation stage, number of species to be cultured, culture system based on production technology and target market. Moreover, a self-sustaining fish farm is expected to have the hatchery, feed mill, outdoor production ponds and fish integrated facilities centered at the same place or nearby (Adegbeye *et al*., 2020).

3.1. Hatchery

This is a place for artificial breeding, hatching, and rearing through the early life stages of animals (FAO, 2013). It contains a re-circulatory system and series of indoor concrete tanks for raising fish. The re-circulation aquaculture systems (RAS) represent a new and unique way to farm fish. This system rears fish at high densities, in indoor tanks with a "controlled" environment. The functional parts of a RAS include growing tank, sump of particulate removal device, biofilter, oxygen injection with U-tube aeration and, water circulation pump (Aich *et a*l., 2020). The biological filter (biofilter) composed of a media (corrugated plastic sheets or beads or sand grains) upon which a film of bacteria grows. The bacteria provide the waste treatment by removing pollutants (fish waste and unused feed). A sump (clarifier tank) is used to prevent the excessive accumulation of fish excretory products and waste feed. Effective diffusion of pure oxygen gas into a liquid (water) is best ~~a~~ccomplished using a U-tube oxygenation, counter-current flow injectors, or micro-bubble devices (tubes or fine wet stones) (Mohammadpour *et al.*, 2021). Furthermore, there are also concrete tanks with aerators that supply oxygen, which is used to hold brood stock during breeding and also for raising hatchings to fingerlings and

even juvenile stages within the hatchery complex (Akinwole & Faturoti, 2007).

3.2. Feed mill

Feed manufacturing and the associated quality control programme are keys to successful fish culture. The feed mill and its laboratory comprised of different machines, which include extruders, grinders (hammer mills, attrition mills, roller mills), pelleting machines, drying and packaging facilities (Anyim *et al.*, 2020). Dry feeds may be ground, sifted, screened, mixed, compressed, expanded, texturized, coloured and flavoured (Tangendjaja, 2015). By one or more of these processes, a wide variety of ingredients can be prepared into a standardized and quality product. Since most fish have size and texture preferences and often react to colour, odour, lavour and processing research is an integral part of fish culture. Processes involved in the manufacture of fish feeds include grinding, mixing, pelleting, cooling and drying (Shanthi & Bhuvaneshwari, 2021; Okolie *et al*., 2021).

(i) Grinding: Grinding or particle-size reduction is a major function of feed manufacturing. Many feed mills pass all incoming ingredients through a grinder for several reasons (Shanthi & Bhuvaneshwari, 2021). This includes reduction of clumps and large fragments size; some moisture is removed due to aeration and additives such as antioxidants may be blended. The grinding of ingredients generally improves feed digestibility, acceptability, mixing properties, pelletability, and increases the bulk density of some ingredients (Anyim *et al.*, 2020). It is accomplished by many types of manual and mechanical operations involving impact, attrition, and cutting.

(ii) Mixing: The main reason of mixing feed is to start with a certain assortment of ingredients called a "formula", totaling some definite weight. This is processed so that each small unit of the whole, either a mouthful or a day's feeding, is the same proportion as the original formula (Mmanda *et al*., 2020). Mixing is recognized as an empirical unit operation, which means that it is more of an art than a science and must be learned by experience. Example of mixers include: horizontal mixer, vertical mixer and liquid mixer.

(iii) Pelleting: The transformation of a soft, often dusty feed into a hard pellet is accomplished by compression, extrusion, and adhesion. The general process involves passing a feed mixture through a conditioning chamber where 4 to 6 percent water (usually as steam) may be added. Moisture provides lubrication for compression and extrusion and in the presence of heat causes some gelatinization of raw starch present on the surface of vegetative ingredients, resulting in adhesion. Within 20 seconds of entering the pellet mill, feed goes from an air-dry (about 10-12 percent moisture) condition at ambient temperature, to 15-16 percent moisture at 80-90°C. During subsequent compression and extrusion through holes in a ring' die, friction further increases feed temperature to nearly 92°C. Pellets discharged onto a screen belt of a horizontal tunnel drier or into a vertical screened hopper are air-cooled within 10 minutes to slightly above ambient temperatures and dried to below 13 percent moisture (Anyim *et al.*, 2020) .

(iv) Cooling and drying: The temperature imparted to pellets in the process of their manufacture assists the removal of moisture by the air-drying process. Generally, within ten minutes after extrusion, hard pellets are cooled to ambient temperature and brought to

a moisture content slightly above that of the entering soft feed. This may be done by spreading pellets in a thin layer on the floor and blowing air over them. Commercially, it is done by passing the hot pellets through a vertical or a horizontal chamber designed to bring air at ambient temperature into intimate contact with the outer surface of the pellets (Mmanda *et al*., 2020).

3.3. Ponds

This is another important component of fish farming. It is another form of rearing facilities of fish; ponds can be earthen or concrete be it indoors or outdoors. The earthen ponds are easier to manage and faster production is attained. Natural and supplemented feed is provided for fish to consume (Anyim *et al*., 2020). Concrete ponds otherwise called concrete tanks are made from blocks, plain concrete slabs or reinforced concrete. It is commonly used where land is not suitable or available for earthen pond construction. There are also plastic tanks made from fiber glass or ordinary plastic as well as wooden troughs (Xiong *et al.*, 2021) .

3.4. Integrated fish facilities

This combines the raising of fish and production of other domestic animals as well as edible plants. This reduces external inputs and cost of production and reduces environmental pollution due to waste conversion and utilization (Watt, 2019). Fish can be raised with poultry, piggery, livestock, duck, rabbit or grass cutter, rice, vegetable production, plantain or banana or pineapple productions (Adegbeye *et al*., 2020).

4. Design and Establishment of Self-sustaining Fish farm

For the best of designing a self-sustaining fish farm, the level and design of production play an important role (Yacout *et al*., 2016). Therefore, it is essential to know if the fish farm is extensive, semi-intensive or intensive and whether it is monoculture, polyculture or integrated system (Medeiros *et al*., 2017). By that, the following details illustrate various qualities of fish farm structure for successful self-sustained fish firm.

4.1. Pond design

Pond systems are the most common method of fish culture (Xiong *et al.*, 2021). Water is maintained in an enclosed area by artificially constructed ponds where the aquatic animals such as the finfish and shellfish are reared. The ponds may be filled with canal water, rain water, bore-well water or from other water sources. The ponds are of different sizes and shapes; earthen ponds range from small (less than 0.5 hectare) to medium (0.5-1.0 hectare) and large (1hectare and above) the concretes are circular or rectangular with depths of between 1 and 1.2 metres (Wikberg & Ab, 2019).

Considering the layout of ponds, the size as well as shape of pond need to fit the topography of the land (Triyatmo & Solin, 2021). If more than a pond is to be constructed, the design should be done side by side with a common embankment and separate inlets and outlet (Spellman & Drinan, 2014). Inlets and outlets of water should be constructed at the shallow and deepest part of the pond respectively. The shallow point should not be more than 1.0m and deepest part not more than 1.5m. There are 2 basic types of ponds; embankment and excavated ponds. Embankment ponds are constructed by damming a small stream and excavated

ponds are constructed by digging out an area fed by springs and runoff, borehole or well (Spellman & Drinan, 2014).

4.2. Water re-circulatory aquaculture system

This is a system that should be located in the hatchery complex. It should be either re-circulates water or passing it through only once (Aich et al., 2020) . However, it is advisable to be re-circulatory for the sake of suitability of hatchery control. It composed of four components; culture chamber (tanks vary in shape and size; rectangular, circular, or oval in shape); primary settling unit; biological filter and secondary settling chamber (Triyatmo & Solin, 2021) . The general configuration or design of the system is as follows:

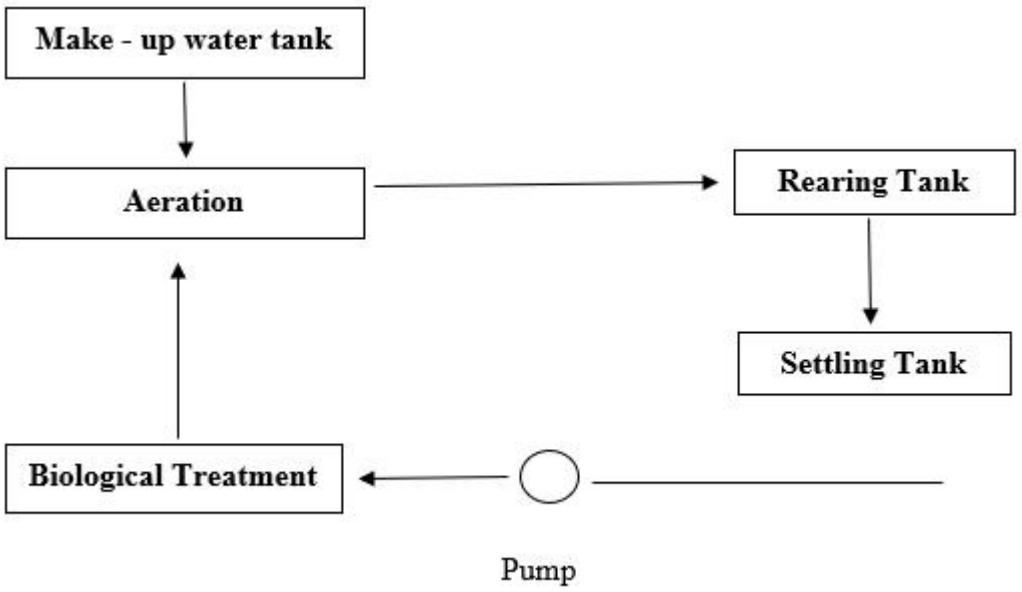

Figure 1: Schematic configuration of re-circulatory system, modified from (Kibenge & Powell, 2020)

4.3. Integrated fish farm

This fish farm is designed to fit the type of animal or plantation to be reared or planted alongside raising of fish (Fig. 2). Possible animals and plants that may accompany the fish farm due to their contribution and harmony with fish farm include but not limited to the following:

(i) Duck - fish culture: The ducks contribute fish production as well as producing eggs and meat. A simple shelter is built next to the fish pond. Here the fish depends largely on duck manure, spilled duck feed, and microscopic animals and plants made plentiful by the presence of the ducks (Biswas, 2015).

(ii) Pig-fish culture: A pig pen is built with 1 to 1.5sq m of floor space per animal on the pond embankment. 30-40 pigs can be raised per hectare of pond area. Pig attains slaughter size after 5-6 months so it can raise alongside fish pond. Kitchen waste, grasses and other green fodder eaten by pig are converted into manure, which can be used to fertilize fish ponds (Watt, 2019).

(iii) Fish-poultry farming: A wooden building with pillars is raised at the edge of the pond

with wooden slab floor. The building contains cages that will serve as house for the birds. The droppings from the birds directly fall into the pond to fertilize the water, which give rise to phytoplankton and zooplanktons and other invertebrates. This serves as natural food of fish. (iv) Fish - rice farming or vegetables: Fish is raised along channels that feed the ponds with water; depending the species, it is raised in the same place where rice is been cultivated (Watt, 2019).

5. Operational Practices on Self-Sustaining Fish farm

It is not enough to establish a fish farm without considering operational practices. Once these facilities are design and established, there are several vital operations that need to be carried out to sustain the fish farm. Some of the practices include the following assessments:

5.1. Water quality

Fish need quality water supply to survive, grow as well as reproduce (Tavares & Santeiro, 2013). Water with no pollutants contains high dissolved oxygen, and does not have excessive organic matter. Therefore, fencing a pond is needed to prevent livestock from trampling on the pond banks, which causes pond shallowing, muddy water, and loss of fish. Fences should be 50 to 100 feet from the pond bank and completely enclose the pond (Biswas, 2015). A vegetated border is needed at least 50 feet wide that will reduce soil erosion and the amount of fertilizer and pesticides entering the pond (Blicharska et al., 2016). Trees along the shoreline are desirable for shading and nutrient uptake. Water clarity should be at least 18 inches throughout the year and is necessary for plankton production (Tavares & Santeiro, 2013).

5.2. Fish stocking

The choice of fish to stock is very important and depends on the goals and resources available to the pond owner (Agostinho et al., 2010). Moving fish from a local lake to the pond, is not recommended (Ngugi *et al*., 2007). This can cause fish diseases and stocking a wrong fish species in an environment. Therefore, stocking pond with the right species and also the number of fish is very important. Overstocking of the pond with fish is also a bad practice, which can affect fish growth and even survival (Agostinho et al., 2010).. For instance, catfish is the best species to stock if the pond is less than 1 acre. Two or even three different species of fish can be raised in the same pond especially those with different feeding habit.
The best management option when the pond becomes out of balance and overpopulated is to remove the fish population especially if the pond can be drained. Fish will survive in very small pools of water away from the main body of water.

5.3. Fish feeding

The amount of food produced in the pond determines the productivity of the pond and the weight of fish. All ponds produce some natural food for fish but sometimes not enough to obtain the desired weight. Supplemental feeding is usually not required, but in some cases where the harvest demand is high or where large fish are desired, fish feeding may be beneficial (Shanthi & Bhuvaneshwari, 2021). Formulated fish feeds in pellet form are very common and available in a sinking or floating form. The floating pellets are advantageous because the person feeding the fish is able to see whether or not the fish are eating the feed, since the feed floats (Anyim *et al.*, 2020). Artificial feeding will also increase fish weight. Fish feeders are very useful, and can be used in almost

any pond for a productive and easy way of increasing fish weight (Mmanda *et al*., 2020).

5.4. Fish kill

The most common cause of fish kill is suffocation, which occurs when aquatic plants do not produce enough oxygen to the fish to breath (Helfrich, 2009). Once fish suffocation starts, it is too late to stop it. Fish kills in general can be best prevented by properly controlling nutrient inputs and overabundant aquatic vegetation (Agostinho *et al.*, 2010). Circulating the water either by motor-driven air compressors or wind driven baffles and artificially aerating is very important to stir up organic materials and result in more oxygen consumption as the materials decay (Aich *et al*., 2020). Make sure no fertilizer, herbicides, insecticides or organic run-off enter the pond (Helfrich, 2009).

5.5. Harvest

A balanced pond fishery can be established with the initial stocking. Maintaining that balance requires the pond owner to manage the harvest, which is usually the most difficult part of pond management. Although there are no hard and fast rules for managing the harvest, the key is to practice a conservative harvest (Ngugi *et al*., 2007).

5.6. Record keeping

Keeping accurate records of numbers and sizes of fish caught in the pond will help to evaluate the status of the fish populations and if any additional management is needed (Akinwole & Faturoti, 2007). Periodic review of these records to see if there are any differences in the number as well as size or kinds of fish in the pond are important (Saini, 2016).

5.7. Managing other animals

To ensure that the fish farm is secured, the predators of fish such as snakes, monitor lizards, toads and fish-eating birds should be avoided since they are able to affect ponds in their own way (Musingi & Mahianyu, 2021). For the best way of controlling predators, the use of traps is the most effective, practical and environmentally safe method. Covering the ponds with nets after stocking with fish is also an important step in controlling these animals (Musingi & Mahianyu, 2021).

5.8. Aquatic weed control

Aquatic plants are essential and beneficial to the pond community of the fish (Retna Melani *et al*., 2022). Aquatic plants provide living areas, shade, food and cover for the fish and organisms of the pond community. Control is not recommended if the vegetation covers less than 20 to 25% of the pond's surface. However, when aquatic vegetation does become overabundant, covering more than 20-25% of the pond, it can cause problems. Thus, the control is recommended (Durborow *et al*., 2007). Aquatic vegetation also uses nutrients that could go into producing fish food organisms. Excessive aquatic vegetation offers unneeded protection to small fish from predators and often results in overpopulation (Ngugi *et al.*, 2007). There are several ways to control aquatic vegetation in ponds. Hand pulling, cutting, or raking aquatic vegetation may be the simplest and least expensive. Placing permeable filter fabric on the bottom can control vegetation in specific areas of the pond. Registered and approved aquatic herbicides can be used to control vegetation and another alternative may be biological control (Durborow *et al*., 2007). Do not apply aquatic herbicides around or in the pond on rainy or cloudy days else will cause fish kill (Vagh et al., 2021).

6. Conclusion

Generally, self-sustaining fish farm comprises of multi-species rearing with income raising activities. Therefore, strengthening of this system by community would be advisable at all scale of social and financial aspects. It is affordable and productive even to the low-income farmers. The practices described in this review revealed the possible techniques to be applied while considering integrated fish farm. Thus, it is recommended to adhere to certain activities while bringing innovations needed to achieve sustainable and affordable aquaculture. Particularly, Nigeria as a country with high potential aquacultural facilities, should emphasize this style for the best way of complying to the market demand of its population. Furthermore, this system would help in fighting malnutrition through combination of rearing other animal husbandry, plantation and fish farm.

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