Journal of Aquaculture
Research & Development

Maulu et al., J Aquac Res Development 2019, 10:4
DOI: 10.4172/2155-9546.1000567

Review Article Open Access

A Review of the Science and Technology Developments in Zambia's Aquaculture Industry

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Abstract

The application of science and technology developments in aquaculture is very crucial for the sustainable development of the industry. This paper provides an overview of the current developments in science and technology used in Zambia's aquaculture industry. Various developments particularly in aquacultural species and culture models, aquaculture production systems, fish feeds and nutrition, water environmental management, and fish health and disease management have been discussed. While some breakthroughs in science and technology have been presented, the review has indicated that the country's aquaculture industry is still lagging behind in some critical areas as the majority of producers are still using traditional technologies which have made it difficult for them to make significant contributions to fish production. As a result of this lag and other reasons, the country has witnessed an unprecedented importation of fish to meet the deficit and the ever-increasing demand. Therefore, efforts to accelerate and sustain aquaculture industrial development in Zambia must address such areas of science and technology as fish genetic breeding and improvements, fish health and disease management, sustainable feeds and nutrition, production systems, and water environmental management

Keywords: Aquaculture; Development; Production; Science; Technology; Zambia

Introduction

Aquaculture remains the fastest growing food-producing sector globally, with 80.0 million tonnes of food fish, 30.1 million tonnes of aquatic plants, and 37,900 tonnes of non-food products recorded in 2016 [1]. The sector has experienced rapid growth over the years due to the growing demand for aquatic products [2]. This rapid growth has witnessed a number of challenges to the sector's sustainable development [3]. These challenges include species improvement and domestication, combating diseases and epizootics, production facilities, development of appropriate feeds and feeding mechanisms, as well as water-quality management [4,5]. However, the scientific and business communities are responding to the challenges and opportunities inherent in the growing aquaculture sector with research efforts aimed at generating novel technologies that mirror the diversity of the industry [4].

Despite aquaculture being the fastest food production sector in the world, production in Africa has not been able to catch up with this global trend in spite of significant natural resources, and a high demand for fish products [6]. The majority of fish products currently produced in Africa come from capture fisheries and the remaining small proportion coming from aquaculture [1]. One major challenge facing the sustainable development of aquaculture in most African countries has been the sharing of scientific discoveries and technology both between and within countries. However, the major consideration regarding all technology transfer to the aquaculture sector requires the full consideration to the protection of wild aquatic diversity and possible impacts on the sovereignty and economy of rural and subsistence populations [5].

Some important science and technology developments in aquaculture, however, have been reported in some African countries [7]. For example, the development of the Akosombo strain of Tilapia through selective breeding in Ghana has contributed to the booming of Tilapia industry in that country. In Zambia, aquaculture researchers have relied largely on trying to adapt the science and technology developed elsewhere to local conditions [8]. Although the country's aquaculture industry holds huge potential for increasing production, little progress has been made in scientific and technological advances. Aquaculture research in Zambia, however, is mandated to design and facilitate the adoption of science and technology for aquaculture production enhancement, thereby increasing food security in the country. This paper was aimed at reviewing the science and technology development in Zambia's aquaculture industry and their application. It also highlighted the major gaps that need attention for sustainable industrial development.

Literature Review

Zambia's aquaculture industry overview

Zambia is a landlocked country located in the southern part of Africa with a total surface area of 752,614 km^2 [9]. The country has abundant land and freshwater resources suitable for aquaculture production [10]. Zambia is estimated to contain 15 million hectares of water in form of rivers, lakes and swamps, and another 8 million hectares of wetlands representing huge natural resources that provide the basis for aquaculture industry development [11-13]. Based on soil conditions, water availability and temperature range, Zambia has been classified as a country that has good conditions for aquaculture, especially with Tilapia species [8] (Figures 1 and 2).

Aquaculture production in Zambia has experienced rapid

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Received March 25, 2018; **Accepted** April 22, 2019; **Published** April 29, 2019

Citation: Maulu S, Munganga BP, Hasimuna OJ, Haambiya LH, Seemani B (2019) A Review of the Science and Technology Developments in Zambia's Aquaculture Industry. J Aquac Res Development 10: 567. doi: 10.4172/2155-9546.1000567

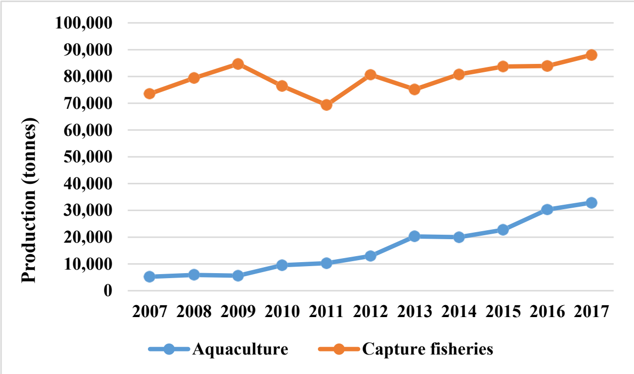

Figure 1: Overview of aquaculture and capture fisheries production in Zambia (2007-2017).

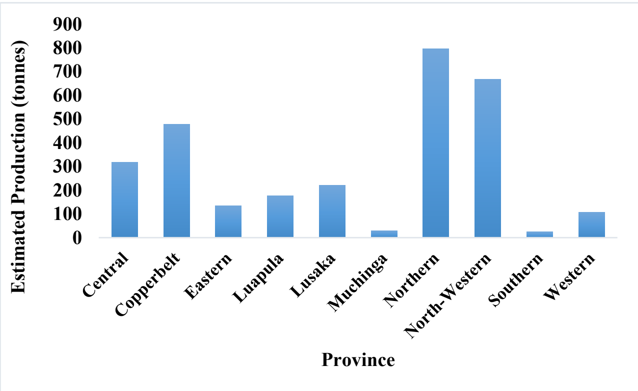

Figure 2: Distribution of small-scale production in Zambia [29].

growth in recent years and likely to play a significant role in food and nutrition security of the country [14]. However, the industry has not been able to fully respond to the increasing demand for fish due to many challenges of which the major ones include lack of access and capacity to obtain quality fish seed and feeds [15]. A significant increase in production from aquaculture has been recorded over the years, and this has been attributed mainly to the emergence of large-scale commercial aquaculture producers from the private sector [12]. Recent estimates by the Zambian Department of Fisheries (DoF) indicates that Aquaculture contributed about 32,888 tonnes of fish representing 27% of the total national fish production recorded in 2017 (Figure 2). Capture fisheries, on the other hand, contributed the remaining 73%. Although production from both capture fisheries and aquaculture has been increasing over the years, the gap in production is significantly reducing with aquaculture growing at a faster rate compared to capture fisheries (Figure 1). The national fish deficit, however, was estimated at 45,000 tonnes in 2014 [16,17]. Meeting this deficit will require innovations in science and technology to improve current aquaculture techniques and applying novel technologies to sustainably expand the production.

Currently, Zambia is ranked among the major aquaculture producing countries in Sub-Saharan Africa and the leading producer of farmed fish in the Southern African Development Community (SADC) region [10,12]. The major drivers of the increase in aquaculture production recorded in recent years have been the emergence of large-scale commercial producers and private investment in fish feed both of which have been driven by high national demand for fish [12].

Science and Technology Developments

Cultured species and culture models

Cultured species: Aquaculture in Zambia, with a few exceptions, is still largely relying on the production of mostly unselected, semi-natural stocks or isolated populations that are subject to inbreeding [10]. Little, so far, has been done to embrace the understanding of fish genetics and fast advancing science of molecular biology utilized by other developing countries such as Ghana, Kenya, Egypt, and Uganda. However, meeting the demands for sustainable supplies of aquatic products in future will depend upon continued progress in applying practical approaches of genetic improvement in the aquaculture industry [4]. Additionally, studies have shown that classical breeding programmes such as selective breeding and crossbreeding and hybridization are the mainstream of species genetic improvement [18-20].

In Zambia, aquaculture practices are based on the culture of freshwater species mainly from the Cichlidae family. The commonly cultured indigenous species include the three spotted Tilapia (*Oreochromis andersonii*), the green-headed Tilapia (*Oreochromis macrochir*), the red-breasted Tilapia (*Tilapia rendalli*) and Tanganyika Tilapia (*Oreochromis Tanganicae*) [21-23]. Other potential indigenous species include *Labeo altevelis*, *Oreochromis mortimeri* and *Clarias gariepinus*. However, little has been done to determine their viability for aquaculture [8]. On the other hand, a number of exotic species have been used in aquaculture, including the common carp (*Cyprinus carpio*); the Nile Tilapia (*Oreochromis niloticus*); and the red swamp crayfish (*Procambarus clarkii*). These exotic species were introduced with the aim of increasing fish production. However, there has been a growing concern globally regarding the use of exotic species in aquaculture due to huge risks involved such as loss of genetic diversity and transmission of epizootic disease.

Oreochromis niloticus has been the major exotic species cultured by commercial aquaculture producers in some parts of the country permitted by the government because of its fast growth and hardiness compared to the indigenous species [10,24]. A recent study by Kefi & Mwango [25], however, revealed that there was no evidence to indicate that farmers using the invasive *Oreochromis niloticus* had better productivity performance compared to those using the closely related indigenous species such as *Oreochromis andersonii*. The authors further argued that if exposed to genetic improvement, it is likely that the indigenous tilapia species will outperform the invasive Nile Tilapia in productivity. More genetic related studies on fish such as genetic characterization of most important indigenous species in Zambia is an urgent need for future development.

The cultured species may be raised either as mono sex or mixed sex. In mono sex, only a single sex species either all males or all females are raised. The practice of culturing all male Nile Tilapia (*Oreochromis niloticus)* is preferred in aquaculture because the males grow faster than the female fish. The production of all male Tilapia in Zambia currently relies on the use of the hormone 17 alpha-methyl testosterone for sex-reversal. However, the use of hormones in food animals is increasingly receiving public concerns related to food safety. According to Subasinghe et al. [5], the development of techniques for producing mono sex populations will continue to be important in aquaculture. There is a need to identify and promote the use of safe and environmentally friendly practices. In mixed-sex, both male and female sexes of a particular species are cultured together. The practice is common among small-scale producers and is considered a traditional practice that leads to overcrowding of the fish due to early reproduction of Tilapia. It is reported that farmers who use sex-reversed species usually have higher productivity compared to those that use mixed sex species [25].

Culture models: The country records three basic culture models: Monoculture, Polyculture, and Integration as discussed below:

- **Monoculture:** In this culture model, only one species either mono sex or mixed sex, are raised in a culture facility, usually for better productivity. This practice is mainly employed by large-scale commercial aquaculture producers in Zambia where cages are the major culture facilities used. The advantages of this model include uniform growth and easy management of the production system.

- **Polyculture:** This model involves the culturing of more than one species of fish either mono sex or mixed sex in the same culture facility. The main advantage of this practice is that there is better utilization of resources in a culture facility since different species utilize different pond trophic levels. In Zambia, this method is normally used between the indigenous Tilapia species and the exotic common carp and or catfish. However, on average, this model is not very common among the farmers in the country mainly because most farmers have little understanding of the benefits and better farming practices.

- **Integration**

This refers to the production, integrated management and complete use of aquaculture, agriculture, and livestock, while emphasizing on aquaculture [26]. The aim is to obtain better productivity in both or among participating systems. The main advantage of this model lies in the optimum utilization of farm resources such as water, land and farm wastes. In Zambia, this model is more common among small-scale farmers, and the commonly integrated systems include fish and ducks, fish and pigs, and fish and crops (vegetables), with fish and pig being the most practiced [8]. However, it is likely that there is a lack of proper knowledge on the full utilization of this model among most farmers in the country. There is a need for more studies in this area to explore the viability of this model, especially among the small-scale farmers according to their specific local conditions. A lot of opportunities exist for integrating aquaculture with other agriculture systems to enhance farm productivity while minimizing production costs.

Aquaculture production systems

Like in many other developing countries, aquaculture production systems in Zambia are categorized into extensive, semi-intensive and intensive based on the level of production, capital investment, labor, and management practices employed [10]. These production systems have been diversified over the years than they were in the early years of its introduction when earthen ponds were the major systems used. Today, reservoirs, earthen and concrete ponds, tanks, hapas, and cages are widely used countrywide depending on where they are applicable [8].

Extensive production systems

In these production systems, the cultured organisms depend entirely on the occurrence of natural foods primarily plankton. There is no intentional supplementary feeding and productivity is usually very low [10]. The system is often characterized by the use of traditional earthen ponds or reservoirs, and commonly practiced in rural communities, probably because it is cheaper and does not require much technical know-how to operate [27]. The majority of the small-scale fish farmers under this system produce fish mainly for household consumption.

Semi-intensive production systems

These systems involve the deliberate enhancement of plankton (Natural fish food) through pond water fertilization, mainly using animal wastes [27]. The fish are occasionally supplemented with artificial feeds to promote growth. Well-designed earthen, and concrete ponds characterize this system as the investment costs are relatively higher and require some level of technical know-how if reasonable profits are to be realized. The majority of the small-scale fish farmers in Zambia are represented by this category.

Intensive production systems

These systems are characterized by high investment costs, and a high level of management resulting in higher profits [10]. The fish is fed using artificially prepared diets to enhance production within a short period of time possible. Suitable liming materials, like agricultural lime, are also applied, especially in ponds to stimulate productivity and for disinfection. Large-scale commercial aquaculture producers in Zambia, are represented by this system. The main culture facilities in this system are cages and concrete ponds. They involve higher stocking densities of mono sex species, mainly the exotic *Oreochromis niloticus*, and the indigenous *Oreochromis tanganyicae* [28].

Although all the three production systems discussed above exist in Zambia, they are rather narrowed into small-scale and large-scale commercial production [10]. Small-scale producers are found in all parts of the country (Figure 2), while large-scale producers are only found in certain provinces of the country including Lusaka, Luapula, Southern and Copperbelt Provinces where conditions are favorable for their production capacity. Generally, small-scale production is very low coupled with slow percent increase (0.9%) observed between 2016 and 2017 (Table 1). The major factors leading to low production by small-scale producers include lack of access and capacity to obtain quality fish seed and feeds, and inadequate extension services. On the other hand, production from large-scale producers has continued to rise representing the largest contribution to the overall aquaculture production. In 2014, large-scale commercial aquaculture production contributed about 71% to the overall aquaculture production, while small-scale fish farmers contributed the remaining 29% [10]. In 2017 however, production from large-scale commercial aquaculture (land-based and cages) accounted for about 79%, while small-scale contributed only about 21% to the overall production (Table 1). Interventions aimed at mitigating the major challenges affecting small-scale producers will require demand-driven extension services with appropriate delivery methodologies [29,30].

Fish feeds and nutrition

Fish feed plays a significant role in aquaculture as it accounts for

Aquaculture producers	2016	2017	% Increase
Small-Scale (Including small water bodies) (tonnes)	6,844	6,905	0.9
Large-Scale (Land-based and cages) (tonnes)	23,441	25,925	10.6
Total Production (tonnes)	30,285	32,888	8.6

Table 1: Contribution of small-scale and large-scale commercial production to total aquaculture production [30].

about 50% of the total fish production cost [31]. Nutritional status is considered as one of the most important factors that determines the quality, and ability of fish to resist diseases [32]. Feed types used for aquaculture in Zambia are generally categorized into single ingredient, fertilization only, commercial feed, a single ingredient and fertilization, and fertilization and commercial feed [25]. The use of commercial feeds is most common among the large-scale commercial producers resulting in higher productivity. The small-scale producers usually attempt to feed and fertilize their ponds in integrated systems using locally sourced materials [33]. However, significantly higher productivity has been reported among small-scale producers using commercial feeds compared to those using the other types [25]. Generally, feed by most small-scale farmers is categorized according to three different technologies: pond fertilization/manuring, on-farm feed or pelleted commercial feed application. Musuka and Mainza [34] reported that the majority of small-scale farmers are dependent on animal wastes to fertilize their ponds and nourish fish through a natural bloom of plankton.

On the other hand, the rapid growth of the large-scale commercial aquaculture producers recorded in recent years has stimulated the development of fish feed manufacturing industry mostly from the private sector that produces four different categories: fry mash, juvenile crumble, starter pellets and grower pellets [10]. However, these feed manufacturing companies are still importing most of their feed micro-ingredients (Vitamins, fishmeal, and premixes) making the prices of fish feed high [10]. Therefore, due to limited financial capacity of the small-scale farmers, and inaccessibility of these feeds by rural farmers, these companies are viewed as more favorable to the large-scale commercial aquaculture producers.

Broadcasting or hand feeding is the most common form of feeding in most aquaculture production systems in Zambia. With the current rapid growth of the large-scale commercial fish producers, it is likely that automatic feeders and other advanced technologies will be adopted in future. Aquaculture nutrition in the future will require a better understanding of the basic nutritional requirements especially for most important cultured species such as *O. andersonii*, *Tilapia rendalli* and *O. macrochir* coupled with innovative methods of administering these nutrients in ways that minimize environmental impacts.

Water environmental management

In Zambia, issues related to aquaculture environment are regulated under appropriate legal instruments relating to environmental protection and species use. Some of these regulatory instruments are the Fisheries Act 21 of 2011, and subsequent fisheries regulations of 2012, the Zambia Environmental Management Agency (ZEMA) Act 12 of 2011 and the Water Management Act 21 of 2011. These all have the mandate to ensure the use of best aquaculture practices to minimize the negative impact of fish farming practices on the environment. However, farmers and potential farmers view these environmental considerations as stumbling blocks to the development of both land-based commercial fish farms and cage culture [28]. This is due to the reportedly high fees charged to do Environmental Impact Assessment (EIA) studies before the commencement of operations.

Aquaculture activities such as power input, transport, waste-water discharge, and feed production can contribute to greenhouse gas emissions [35]. Greenhouse gases such as Carbon dioxide (CO_2) are believed to be the major contributors to climate change [36]. Today, climate change has become a common topic, and is considered a global aquaculture production risk as well as a major threat to the quality and quantity of production [37-39]. Moreover, Zambia is reported to be among the most vulnerable countries to climate-induced changes in fisheries and aquaculture [40]. Therefore, aquaculture industry in Zambia needs to develop and prioritize the use of environmentally friendly practices that minimize the emission of greenhouse gases.

Currently, water environmental management and protection issues related to aquaculture in Zambia are not clearly defined, especially for the small-scale producers. Although they represent the largest proportion of aquaculture producers, small-scale producers are usually neglected in water environmental management regulations and their production practices are rarely monitored. Wastewater treatment from aquaculture production facilities is also poorly reported among small-scale farmers. However, a few large-scale commercial farmers are able to treat wastewater from their production facilities. Innovations in Information and Communication Technology (ICT), such as the application of sensors and monitoring tools to better manage the water environment, and to protect against catastrophic losses is an important area that requires consideration for future development.

Fish health and disease management

Fish health management has proven to be one of the greatest challenges and prospects affecting the expansion of sustainable aquaculture [4]. The outbreak of epizootic diseases continues to represent one of the most important limiting factors for the success of aquaculture production systems in different countries of the world. The mere presence of the pathogen in a culture environment does not necessarily cause disease outbreaks. Instead, the outbreaks usually occur when fish is stressed due to changes in its environment making them more susceptible to pathogens [41].

In Zambia, the commonly applied aquaculture diseases diagnostic technologies are largely based on traditional methods used in parasitology, bacteriology, virology, and mycology. Moreover, there is limited number of experts specialized in fish health and disease control to facilitate the development and application of modern technologies aimed at combating epizootic diseases. Most of the disease outbreaks are analyzed in government learning institutions. So far, aquaculture in Zambia has not experienced serious disease outbreaks, such as Streptococcosis which is reported to cause serious economic losses in Tilapia culture, probably because of the low level at which the industry is performing. However, with the rapid growth of the aquaculture industry observed in recent years, disease outbreaks will likely present a major challenge to the sustainable development of the industry in future, especially for the large-scale commercial farmers. It is also likely that the continued introduction of exotic species to boost aquaculture production will further increase the risks of fish disease outbreaks. Moreover, invasive species have the ability to destabilize ecosystems and potentially drive native species into extinction through hybridization [42]. New diagnostic technologies will be required in future for better understanding of disease transmission to determine constraints on movements of stock to better control the spread of diseases across borders [4].

Fish health and disease management in Zambia currently rely on the intensification of biosecurity measures such as water quality management and reasonable stocking densities to minimize fish stress which weakens fish immune system.

Opportunities for science and technology developments

A number of opportunities exist for the development and application of science and technology in aquaculture to boost production. Aquaculture in Zambia has continued to attract more attention from both the public and private sectors. For example, the Citizens Economic Empowerment Commission (CEEC) of the country has in recent years shown support in the form of credit facilities to small-scale farmers. Additionally, the support from WorldFish center through partnering with local stakeholders to boost aquaculture is likely to trigger more opportunities for development. Aquaculture-related programs are currently being introduced in major institutions in the country. However, these institutions will need to tailor their curriculum to the needs of aquaculture development to promote the development and adoption of science and technological innovations. Opportunities also exist for the stakeholders in aquaculture to partner with national associations and initiatives promoting science and technology developments such as the Fisheries and Aquaculture Society of Zambia (FASOZA), the Engineering Institution of Zambia (EIZ) and the Junior Engineers Technicians and Scientists (JETS) club to design low-cost innovations meeting farmer needs in their particular environmental and socio-economic settings. Importation of technologies is not always the best since it does not usually consider the actual needs of small-scale farmers, but rather biased towards the needs of large-scale commercial producers.

Major challenges in Science and Technology development

Although Zambia's aquaculture industry has experienced rapid growth in recent years, the industry is still faced with many constraints which affect its better performance. Important bottlenecks still exist in the application of science and technology in aquaculture, and these include:

- Inadequate private sector and community investment in fish farming technology (such as culture facilities, feeding practices, fish health and disease control, and fish genetic improvement);
- Limited extension services to promote the transfer the science and technology to fish farmers as well as monitoring the progress to provide relevant feedback to researchers and policymakers;
- Inadequate and untimely funding to government aquaculture research stations to support science and technology developments;
- Inadequate experts specialized in some important areas of science and technology such as fish genetic breeding, Fish health and disease, Feeds and nutrition, and water quality and environmental protection;
- Limited real-time communications that connects universities, aquaculture research centres, non-governmental organizations (NGOs) and industry for better development and dissemination of knowledge on science and technology;
- University/college graduates not taking up fish farming themselves. These could have more confidence in applying the most recent discoveries and innovations in the aquaculture industry. Unfortunately, most universities in the country train students for employment not for skill development.

Conclusion

The future development of the aquaculture industry will rely on the development and application of science and technology in all areas of the industry. Aquaculture production in Zambia has significantly increased in the recent past as it has received great attention from both the government and private investors. However, the industry still holds great potential for increasing aquaculture production to meet the estimated demand. There is more to be done in science and technology for sustainable development. The rapid increase in fish production from aquaculture recorded in the recent years is mainly due to the expansion of the large-scale producers. Sustainable development of the aquaculture industry in Zambia will require addressing the major challenges faced by small-scale farmers.

Recommendations

With regard to the reviewed challenges in Zambia's aquaculture, the following recommendations were made as future developmental strategies:

- There is a need to promote adequate private sector and community investment in aquaculture technology to for production efficiency. This will also promote technology transfer among the aquaculture producers.
- Extension services delivery should be improved and supported to facilitate technology transfer. This will enable research institutions to develop innovations that meet farmer needs.
- In order to facilitate science and technology innovations and transfer in the country, the Zambian government should consider providing adequate and timely funding to the Department of Fisheries.
- There is a need to establish real-time communication that connects universities, aquaculture research centers and industry for better development and dissemination of knowledge on science and technology. This will provide a fundamental foundation for the process of aquaculture innovations and technology development.
- For proper tracking of the progress in innovation and application of technology, the scientific community, industry, government, and NGOs should work towards reaching agreements on mutual goals.
- There is a need to strongly encourage university/college graduates to take up fish farming as a business. These can be useful agents of change.

References

1. FAO (2018) The state of world fisheries and aquaculture 2018: Contributing to food security and nutrition for all, Rome: Italy.
2. FAO (2017) FAO Aquaculture Newsletter. p. 56.
3. Preston N (2016) FISH: CGIAR Research Program on fish agri-food systems, Proposal.
4. Browdy CL, Hulata G, Liu Z, Allan GL, Sommerville C, et al. (2012) Novel and emerging technologies: can they contribute to improving aquaculture sustainability? In: Subasinghe RP, Arthur JR, Bartley DM, De Silva SS, Halwart M (eds). Farming the Waters for People and Food. Proceedings of the Global Conference on Aquaculture 2010, Phuket, Thailand. p. 22-25.
5. Subasinghe RP, Curry D, McGladdery SE, Bartley D (2002) Recent technological innovations in aquaculture. FAO Fisheries Department, Rome, Italy.
6. FAO (2008) National aquaculture sector overview. Zambia. National Aquaculture Sector Overview Fact Sheets. In FAO Fisheries and Aquaculture Department, Rome, Italy.
7. Satia BP (2017) Regional review on status and trends in aquaculture development in sub-Saharan Africa -2015, FAO Fisheries and Aquaculture Circular No. 1135/4. Rome, Italy.
8. Mudenda HG (2009) Assessment of national aquaculture policies and programmes in Zambia. SARNISSA: Sustainable Aquaculture Research Networks in Sub Saharan Africa.

9. Keddy M (2003) Forest cover crisis in the sub-tropics: A case study from Zambia, 1022-B1, FAO.

10. Genschick S, Kaminski AM, Kefi AS, Cole SM (2017) Aquaculture in Zambia: An overview and evaluation of the sector's responsiveness to the needs of the poor. Penang, Malaysia: CGIAR Research Program on Fish Agi-Food Systems and Lusaka, Zambia.

11. ADP (2009) Supporting appropriate, practical, and tested business models for fish farming, 2008-2011. Lusaka, Zambia.

12. Kefi AS, Mukuka RM (2015) The fisheries sector in Zambia: Status, management, and challenges, technical paper no. 3, Indaba Agricultural Policy Research Institute (IAPRI). Lusaka: Zambia.

13. Nsonga A, Mwiya S (2014) Challenges and emerging opportunities associated with aquaculture development in Zambia. Int J Fish Aquat Stud 2: 232-237.

14. Genschick S, Marinda P, Tembo G, Kaminski AM, Thilsted SH (2018) Fish consumption in urban Lusaka: The need for aquaculture to improve targeting of the poor. Aquaculture 492: 280-289.

15. Oladapo O, Yinusa M, Bangwe L, Marttin F, Chimatiro S, et al. (2016) Zambia Aquaculture Enterprise Development Project, Appraisal Report. African Development Bank.

16. Lombanya V, Ng'onga MJB, Chitotela RK, Chungu AM, Kafwaya D, et al. (2014) Report of your committee on agriculture for the fourth session of the eleventh national assembly appointed on Thursday 25th September, 2014, Zambia.

17. Namonje-Kapembwa T, Samboko P (2017) Assessing the Profitability of Small-Scale Aquaculture Fish Production in Zambia. Indaba Agricultural Policy Research Institute (IAPRI), Zambia.

18. Bartley DM, Rana K, Immink AJ (2001) The use of inter-specific hybrids in aquaculture and fisheries. Rev Fish Biol Fisher 10: 325-337.

19. Gjedrem T (2005) Selection and breeding programs in aquaculture. Dordrecht, Springer. p. 364.

20. Hulata G, Ron B (2009) Genetic improvement of finfish. In: Burnell G, Allan G, (Eds). New technologies in aquaculture: improving production efficiency, quality and environmental management. Woodhead Publishing Ltd, Cambridge, UK. p. 58-86.

21. Mudenda CG (2004) The economics of fish farming in Zambia. A report prepared for the FAO.

22. Musumali MM, Heck S, Husken SMC, Wishart M (2009) Fisheries in Zambia: an undervalued contributor to poverty reduction. The Worldfish Center/the World Bank: 16p.

23. Kefi AS, Chimba N, Kancheya C, Mumba DC, Kubiriza KG (2011) Some aspects of reproductive biology of *Oreochromis Andersonii* (Castelnau, 1869), *Oreochromis Macrochir* (Boulenger, 1912) and *Oreochromis niloticus* (Linnaeus, 1758). Malawi j Aquac Fish 1: 32-37.

24. Maulu S, Musuka CG (2018) Assessing the Abundance and Distribution of Tilapia Species in Lake Kariba. Int J Fish Aquac Sci 8: 1-11.

25. Kefi AS, Mwango J (2018) Is the culture of exotic fish species the answer to low fish productivity? A case study on the use of *Oreochromis niloticus* in Zambia. Int J Fish Aquac 10: 129-139.

26. Gomez RG (2011) Integrated fish farming strategies, FIRA Service, World Water Day: Water for Cities, FAO.

27. Mainza RM, Musuka CG (2015) Extent of Small-Scale Fish Farming in Three Districts of Lusaka Province. Int J Aquac 5: 1-12.

28. Musuka CG, Musonda FF (2012) Current and future prospects of commercial fish farming in Zambia. AACL Bioflux 5: 79-97.

29. Department of Fisheries, Zambia (2015) Fisheries and aquaculture statistics: Annual report-I, Ministry of Fisheries and Livestock, Chilanga, Zambia.

30. Department of Fisheries, Zambia (2017) Fisheries and aquaculture statistics: Annual report-II. Ministry of Fisheries and Livestock, Chilanga, Zambia.

31. Rana KJ, Siriwardena S, Hasan MR (2009) Impact of rising feed ingredient prices on aquafeeds and aquaculture production. FAO Fisheries and aquaculture Technical Paper 541.

32. Yengkokpam S, Debnath D (2016) Nutrition and feed technology for produce healthy fish through aquaculture, fish feed formulation, preparation and its importance in Northeast India, Workshop compendium.

33. Bentley G, Bentley M (2005) A review of the animal and aquafeed industries in Zambia. In Moehl J and Halwart M, Eds. A synthesis of the formulated animal and aquafeeds industry in sub-Saharan Africa. CIFA Occasional Paper No. 26. Rome: Italy.

34. Musuka CG, Mainza RM (2015) Extent of small-scale fish farming in three districts of Lusaka Province. Int J Aquac 5: 1-12.

35. Adhikari S, Keshav CA, Barlaya G, Rathod R, Mandal RN, et al. (2018) Adaptation and mitigation strategies of climate change impact in freshwater aquaculture in some states of India. J FisheriesSciences.com 12: 16-21.

36. Cicerone RJ, Nurse P (2015) Climate change: Evidence and causes: An overview from the Royal Society and the US National Academy of Sciences, the Royal Society.

37. Beach RH, Viator CL (2008) The economics of aquaculture insurance: An overview of the U.S. pilot insurance Program for cultivated clams. Aquacult Econ Manage 12: 25-38.

38. Hamdan R, Kari F, Othman A, Samsi SM (2012) Climate change, socio-economic and production linkages in East Malaysia Aquaculture Sector. 2012 International Conference on Future Environment and Energy IPCBEE, IACSIT Press, Singapore.

39. Kaddo JR (2016) Climate change: Causes, effects and solutions: A Honors Projects.

40. Allison EH, Perry AL, Badjeck MC, Adger WN, Andrew NL, et al. (2009) Vulnerability of national economies to potential impacts of climate change on fisheries. Fish and Fisheries 10: 173-196.

41. Amal NA, Saad MZ, Zahrah AS, Zulkafli AR (2015) Water quality influences the presence of Streptococcus agalactiae in cage cultured red hybrid Tilapia, *Oreochromis niloticus* × *Oreochromis mossambicus*. Aquacult Res 46: 313-323.

42. Huyse T, Snoeks J (2013) Tilapia, tracing fish introductions and lateral parasite transfer to indigenous aquatic fauna.