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Present status of aquaculture and the challenge of bacterial diseases in freshwater farmed fish in Tanzania; A call for sustainable strategies

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ABSTRACT

Aquaculture provides significant contributions to household food security, as the capture of wild fish from lakes, dams, and oceans do not meet the current demand for animal protein in Tanzania. Sustainable aquaculture requires well-established regulatory systems and extension services for good pond management practices and maintaining fish health by fish farmers. Fish farming is practiced widely in Tanzania, from small-to large-scale ponds and these farming systems are moving from extensive normal operations (low input demand) to intensive farming (high input demand). However, the industry is largely still operating at a subsistence level with low production. Bacterial infections have been occurring in these fish farms and will continue to be an issue of concern into the future. This review highlights the current challenges, successes, and prospects towards a sustainable aquaculture industry in Tanzania, including: limited extension services mirroring the limited knowledge by farmers regarding pond management practices; the inadequacy of funds to carry out fish disease research or implement a surveillance system; little expertise in fish disease diagnosis and treatment; and poor management options. To minimize disease outbreaks and optimize production in the future, we suggest a strengthening of extension services, augmented with on-farm knowledge transfer. Emphasis should be on pond management practices and fish disease management; the creation of a well-functioning fish disease surveillance system; and strengthening collaborative research on aquaculture between the government research institutions and academia. Establishing small cooperative fish farmer groups within the Aquaculture Association of Tanzania (AAT) for easy access to information is also recommended.

1. Introduction: Aquaculture in Mainland Tanzania

1.1. Geography, main aquaculture regions, and spatial distribution of farms

The number of ponds in mainland Tanzania are increasing yearly (Fig. 1) and are currently estimated at more than 20,000 freshwater fish ponds (MLFD, 2013; Rukanda, 2018). Fish farming is largely practiced in four regions in Tanzania, which each have more than 1000 fish ponds, including Ruvuma (4942 ponds); Iringa (3137 ponds); Mbeya (1176 ponds) found in the southern highlands of Tanzania; and Kilimanjaro (1660 ponds) located in the northern part of Tanzania (MLFD, 2013) (Fig. 2). The scattered pattern of fish ponds is determined by several factors, such as: availability of water; suitable land for fish farming; and awareness and motivation regarding the economic potential in fish farming within the community (URT, 2015, p. 58).

1.2. History of aquaculture development

Aquaculture in mainland Tanzania started in the late 1920s, following the introduction of trout from Scotland to the streams of the Kilimanjaro and Mbeya regions (Balarin, 1985, p. 105). In the 1950s, fish farming started using experimental ponds at Korogwe (in the Tanga Region) and Malya (in the Mwanza Region) (FAO, 2012; Nilsson & Wetengere, 1993). During these times, tilapia fingerlings were supplied from wild stocks in Lake Victoria and the Congo and Pangani Rivers (Rothuis et al., 2014). Later, Nile tilapia (*Oreochromis niloticus*) fingerlings were supplied by the Hombolo Center across mainland Tanzania

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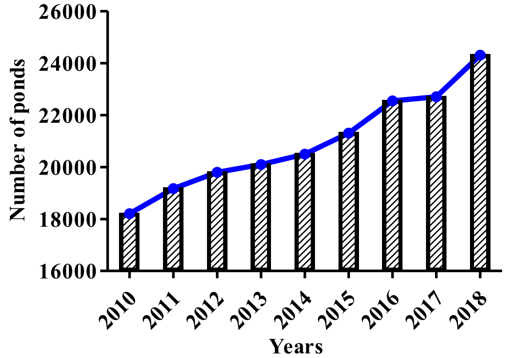

Fig. 1. Number of ponds in mainland Tanzania between 2010 and 2018 (Rukanda, 2018; National Aquaculture report).

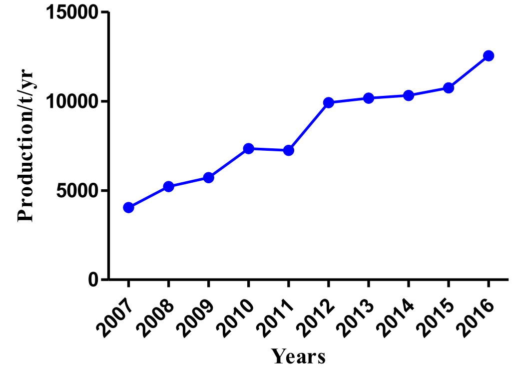

Fig. 3. Overall aquaculture production per year in Tanzania (FAO, 2018a).

(Coche et al., 1994). These fingerlings were distributed by the government to fish farms (both public and private) and to public water reservoirs (Madalla, 2008). Despite this history, aquaculture in Tanzania is still in an infant stage, with an enormous potential for expansion (Mdegela, Omary, Mathew, & Nonga, 2011) as production is increasing (Fig. 3). Fish farming in the country has been traditionally practiced by small farmers who owned small fish farms of up to an average size of 10 m × 15 m (150 m^2). In addition to fish farming, these ponds are also used for other agricultural activities, such as gardening (FAO, 2012; Watengere, 2010). Recently, large-scale fish farms have been opened to attract industrial investment in the country. This was demonstrated by Chenyambuga, Mwandya, and Madalla (2014) in their study of the Mvomero and Mbarali districts which observed an increase in average pond size of about 345 m^2 and 631 m^2, respectively. Such pond sizes are larger than the 150 m^2 reported by FAO (2012) and 300 m^2 reported by Kaliba, Osewe, Senkondo, Mnembuka, and Quagrainie (2006) from the southern and northern highlands.

Mainland Tanzania is dominated by tilapia species of the genus Oreochromis. *Oreochromis niloticus* has become the predominantly cultured species because of its superior growth characteristics (Chenyambuga et al., 2014). Other species include trout and catfish in freshwater, and milkfish and prawn in mariculture (URT, 2016, p. 40).

Aquaculture development in mainland Tanzania has seen changes in organization structure, administration, and regulatory instruments. Until the 1990s, the industry was handled by the Ministry of Tourism, Natural Resources and Environment in the Fisheries Division (Coche et al., 1994) before passing between several Ministries following political changes. The Ministry of Agriculture, Ministry of Agriculture, Livestock and Fisheries, Ministry of Livestock and Fisheries Development, all oversaw the industry prior to its current location in the Ministry of Livestock and Fisheries. Aquaculture has operated administratively under the established Directorate of Aquaculture Division under the last two ministries (Shoko et al., 2011).

The National Fisheries Policy of 2015 is an update of the Fisheries Policy of 1997. The former was published by the Government to boost the development of the fisheries and aquaculture sectors. The policy objective was to develop the sectors for significant progress toward improving food security and nutrition and the growth of the national economy. The policy is executed through key documents: the Fisheries Sector Development Programme; Fisheries Management Plans for the

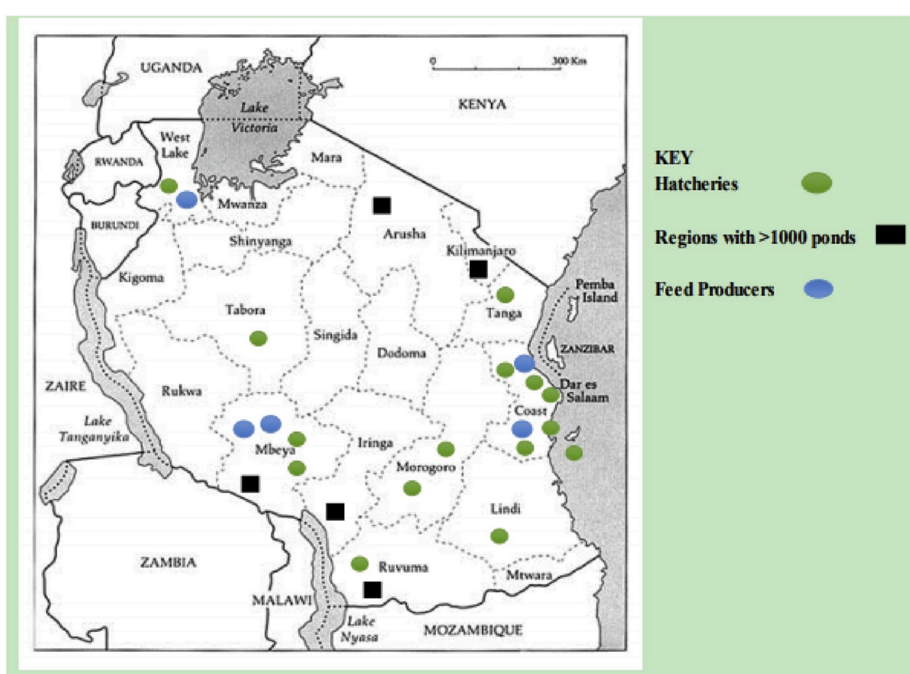

Fig. 2. Map of mainland Tanzania showing regions with large numbers of fishponds (>1000) (Rukanda, 2018).

prawn; octopus, tuna and small-scale artisanal pelagic fisheries; and the National Aquaculture Development Strategy (URT, 2015, p. 58). Legal and regulatory frameworks related to aquaculture are implemented through the Fisheries Act no. 22 of 2003, which is an amendment of the Fisheries Act no. 6 of 1970. There are also other related acts and regulations which complement the Fisheries Act, including the Tanzania Fisheries Research Institute (TAFIRI) Act of 2016. The move towards the independent Aquaculture Development Act of 2019 is in the final stage of incorporating of opinions from stakeholders before it is published in the Government Gazette. In the proposed Act, matters related to diseases, such as notification and biosecurity measures, have been placed under the section of Health and Welfare of Aquaculture Organisms.

1.3. Current contributions to food security and socio-economic factors

Fish resources are an easily accessible source of animal protein worldwide (FAO, 2016) and the same is true in mainland Tanzania. However, fish contributes up to about 30% toward animal protein intake, with a deficit of almost 50% for all animal protein. The impact and contribution of fish produced in these ponds for directly improving household food security are projected to be at the expense of animal meat (Watengere, 2010). However, the value of marketed farmed fish does not bring significant income to these farmers (Watengere, 2010).

The industry is primarily consisted of small-scale integrated freshwater fish farming (Nilsson & Wetengere, 1993; Watengere, 2010). Most of the farmers own an average of one fish pond (Mdegela et al., 2011). Overall production has been low, but it is increasing. In 2013, 3600 tonnes were produced and the production is estimated to be over 4000 tonnes per year at this writing of this review (Rothuis et al., 2014; Rukanda, 2018; Ubwani, 2018). This increase is a result of fish farms occurring more widespread throughout Tanzania and farming systems moving from extensive normal operations (low input demand) to intensive farming (high input demand). However, the industry is largely still operating at subsistence level. The daily demand for fish is still high and production is not enough to meet consumer demand. Mainland Tanzania produces 336,821 tonnes of fish annually against a demand of 731,000 tonnes; a gap of approximately 480,886 tonnes (Mirondo, 2017; Nachilongo, 2019).

Fish farming practices not only contribute to providing animal protein, but also provide services that include: erosion control, livestock watering, fire control, irrigation, picnicking, swimming, and wildlife enhancement (Watengere, 2010). In addition, Watengere (2010) revealed that fish farmers have acquired political positions because of their involvement in fish farming.

It is evident that the expansion and growth of the aquaculture industry will occur following the efforts made by both the public and private sectors to improve fish farming in the country. This will create demand for improved fish research and fish disease diagnosis, treatment, and control (Akoll & Mwanja, 2012; MLFD, 2013), which may become major challenges to sustainable aquaculture in the future (URT, 2015, p. 58).

2. Review methodology

A systematic search of publications was done using online internet-based search engines between August 2017 and March 2018. The exact procedures are described in detail by (Phiri, Benschop, & French, 2010). Three search engines (electronic databases) were used in this study, namely the National Centre for Biotechnology Information (NCBI) through Pubmed, Google Scholar, and Science Direct. Search terms and phrases used were: "pond management practices" "Bacteria", "fish disease", "Freshwater farmed fish", "fish disease diagnostic methods", "control strategy", aquaculture "challenges", "prospects", and "Tanzania". In addition, Boolean operators, proximity search, and mapping techniques were employed to expand and identify relevant articles.

Peer-reviewed journal articles, theses, conference papers, book chapters, projects, and government reports were downloaded and reviewed. All papers were screened by reading the titles and abstracts. If these criteria were determined to be relevant, the full paper was read. The references from a read paper were also screened to identify relevant papers that might have been missed by the initial search engine search. Information, facts, evidence, or key messages were extracted from these papers and included within the review.

3. Challenges to sustainable aquaculture in Tanzania

3.1. Limited knowledge by farmers on best management practices

Biosecurity measures and good pond management practices coupled by other fish disease control methods, such as disease treatment and vaccination, are of paramount importance for sustainable aquaculture. While these best practices are implemented in developed countries, efforts must be made to train farmers on biosecurity measures, pond management practices, and the potential risks of bacterial diseases in developing countries like Tanzania.

Chenyambuga et al. (2014) revealed that fish farmers had little knowledge of biosecurity measures and pond management practices and 25% of these farmers sourced fingerlings and fry from neighbours while others sourced them from non-governmental organisations (NGOs). However, NGOs did not influence the farmers to source their fingerlings because of good biosecurity measures in their hatcheries, but because they wanted to establish them as continual clients of their supply (Chenyambuga et al., 2014).

Rukanda (2018) pointed out that the reason that fry and fingerlings were purchased from these untrustworthy sources was due to the lack of trusted hatcheries across the country, augmented by a production that is lower than demand. An emphasis on strengthening extension services should be made by appropriate authorities to sustain the industry. This effort should prioritize an increase in the number of on-farm trainings and workshops available to fish farmers. Such workshops would train farmers effectively on how to strengthen biosecurity measures and adhere to proper pond management practices, encouraging farmers to collect fingerlings from trusted sources and well-managed hatcheries; monitor and assess the quality of pond water; disinfect equipment used in handling fish; improve pond worker hygiene; reduce stress level in fish; and restrict fish movement from one body of water to another as regulations require.

3.2. Inadequate extension and advisory services in Tanzania

Extension and advisory services are crucial to a sustainable aquaculture industry. However, due to a low number of extension staff in this field, countrywide extension services do not reach the majority of fish farmers (Mlozi, Sanga, Tumbo, Shetto, & Mwamkinga, 2012; URT, 2011). Ragasa, Ulimwengu, Randriamamonjy, and Badibanga (2016) reported that the country has 8000 extension agents, compared to a demand that is greater than 20,000. Even those extension staff that are available and expected to deliver the skills and knowledge to fish farmers sometimes cannot, due to a lack of transport for making long distance visits.

The use of Information and Communication Technologies (ICTs) has demonstrated a substantial impact in improving extension and advisory services, revolutionising agriculture in India, Ghana, and South Africa (Tarimo & Sanga, 2017). Such strategies could be used by extension centers and fish farmers seeking information on good pond management practices and fish health management. Tarimo and Sanga (2017) proposed the use of mobile phones to enhance extension services to fish farmers, a strategy that has potential in Tanzania, where over 40 million Tanzanians possess mobile phones (TCRA, 2018). Social platforms, such as WhatsApp and Facebook, will facilitate interactive communication between the fish farmers and extension officers, and Skype among extension officers. Therefore, farmers should be encouraged to join those networking platforms for quick access to information.

3.3. Bacterial diseases of freshwater-farmed fish

Infectious diseases are a major concern in fish farming practices and can broadly be categorized as parasitic, bacterial, viral, or fungal diseases. These diseases are usually associated with high mortality and morbidity rates, resulting in negative impacts to farmers, consumers, and the environment (Hasan, Faruk, Anka, & Azad, 2013; Toranzo, Beatriz, & Romalde, 2005). The microorganisms that cause these diseases range from primary pathogens to opportunistic microorganisms (Richards and Roberts, 1978). Bacterial infections and diseases in fish farms are accelerated by a number of factors including: variation in the physical and chemical parameters of pond water, such as increased turbidity, temperature, salinity, pH, water conductivity, and low dissolved oxygen (FAO, 2018; Jacobs & Chenia, 2007; Nadirah, Najiah, & Teng, 2012).

These environmental factors induce stress in fish, which allow them to succumb to infections more easily (Romero et al., 2012). Due to the current nature of aquaculture in mainland Tanzania, the industry has had to deal with the few reported bacterial infections. Addressing this hazard can be accomplished by putting in place proper strategies on how to provide knowledge and skills for proper pond management practices and how to address fish diseases in their farms once outbreaks occur.

Globally, more than 13 bacterial genera have been reported to cause bacterial diseases in the aquaculture industry (Pridgeon & Klesius, 2012). In mainland Tanzania, five genera have been suspected to infect freshwater wild and farmed fish. In this review article, we discuss these bacteria and diseases they cause to provide a state of current knowledge contributing to the implementation of epidemiological studies and surveillance through proper diagnosis and control strategies. The genera are *Aeromonas*, *Pseudomonas*, *Edwardsiella*, *Flavobacterium*, and *Streptococcus*.

3.3.1. Motile aeromonas septicemia (MAS)

Bacterial infections in pond-raised fish are caused by motile members of the genus *Aeromonas*. These include *Aeromonas hydrophila*, *Aeromonas sobria*, *Aeromonas caviae*, *Aeromonas schuberti*, and *Aeromonas veronii* (Azad, Rajendran, Rajan, Vijayan, & Santiago, 2001; Deen, Dorgham, Hassan, & Hakim, 2014).

In Tanzania, the occurrence of motile aeromonads septicemia (MAS) disease reportedly caused mass mortality of wild tilapia in 2009, affecting the livelihood of thousands of people in the surrounding area. Shayo et al. (2012) revealed the presence of bacteria, specifically *A. hydrophila*, *A. caviae,* and *A. veronii* during an outbreak of MAS in 2012. However, the outbreak of MAS of 2009 and that of 2012 reported by Shayo et al. (2012) occurred in wild tilapia at the Mtera hydroelectric power dam. Again in 2012, Shah, Colquhoun, Nikuli, and Sørum (2012) reported to have isolated *Aeromonas* spp. farmed fish in a joint study between mainland Tanzania and Pakistan. A cross-sectional survey study conducted by Mzula et al. (unpublished data) of farmed tilapia in the southern highlands (Ruvuma, Iringa, and Mbeya) and northern zone (Kilimanjaro) established a prevalence of aeromonads infection within apparently healthy fish of 24.6%. Two *Aeromonas* spp were phylogenetically identified: *A. hydrophila* and *A. veronii.* Regular surveillance is required for farmed fish in other regions of mainland Tanzania.

3.3.2. Edwardsiellosis

Edwardsiellosis is an important bacterial septicemia disease in farmed fish and is caused by a gram-negative bacterium, *Edwardsiella* spp. (Nadirahet al., 2012). The bacterium infects farmed catfish in mainland Tanzania as a secondary infection, following lesions developed by a lack of Vitamin C. Catfish are particularly vulnerable when farmed in ponds cast out of concrete. *Edwardsiella tarda* was isolated during a 2016 outbreak in catfish in Dakawa farms, Morogoro (E.D. Mwega, personal communication). Mkemwa (2017) also reported a prevalence of 1.48% of the same bacterium in farmed African catfish (*Clarias gariepinus*) and tilapia (*Oreochromis niloticus*) in Morogoro.

3.3.3. Flavobacteriosis

Flavobacterium spp. is another bacterial disease in Tilapia farms and is highly contagious, especially to fingerlings, resulting in high mortality (IAAH, 2007).

Flavobacterium spp. infections have occurred in the wild and a few tilapia ponds in Lake Victoria at Mwanza and Morogoro (Mwega et al., 2019) and further survey to cover large area is vital. Nonetheless, no outbreaks of Flavobacteriosis have been reported in Tanzania.

3.3.4. Streptococcosis

Streptococcosis is a bacterial disease caused by *Streptococcus* spp. in freshwater-cultured fish. The most common pathogenic *Streptococcus* species affecting fish is *Streptococcus iniae*. *Streptococcus* spp. are gram positive bacteria and cocci are arranged in chains. *Streptococcus agalactiae* is another species affecting tilapia and is linked to the intensive culturing of brood stock (Hernández, Figueroa, & Iregui, 2009). Streptococcosis can cause a mortality of up to 50–70% in tilapia farms (Laith & Najiah, 2014), leading to dramatic economic losses from outbreaks (Fawzy, Osman, Ibrahim, Ali, & Abd-Elrahman, 2014).

Streptococcosis occurs in fish farms throughout Africa, including Egypt (Fawzy et al., 2014). In Tanzania, *Streptococcus* spp. has been observed in apparently healthy tilapia fish in few farms (unpublished data), though disease outbreaks were not reported by these farms. Therefore, an attempt to conduct extensive surveillance is recommended.

3.3.5. Red skin disease

Pseudomonas, the aetiological agent of red skin disease, affects a wide range of freshwater fish species, including tilapia. *Pseudomonas anguilliseptica* is believed to be one of the most significant pathogens for cultured fish (Mastan, 2013). Other important *Pseudomonas* species found in fish cultures are *Pseudomonas aeruginosa* and *Pseudomonas fluorescens,* which are ubiquitous in freshwater ecosystems. Shayo et al. (2012) reported *Pseudononas* spp. caused haemorrhagic septicemia and ulcerative diseases in wild finfish at the Mtera hydropower Dam in the Iringa region, Tanzania. *Pseudononas* spp. were also reported in apparently healthy and diseased fish from ponds in Masasi (Mtwara), Songea (Ruvuma) and Morogoro (Rural and Urban) in 2012 (Shah et al., 2012). Further surveillance in fish farms over a larger part of the country is needed.

3.4. Incapacitated surveillance systems and monitoring fish bacterial diseases in Tanzania

In Tanzania, surveillance and monitoring are managed by the Ministry of Livestock and Fisheries (MLF). Due to inadequate funds, active surveillance of farmed fish diseases has not been a priority. Compared to the well-developed program of monitoring livestock diseases, little has been done for the surveillance of bacterial and other diseases found in cultured fish (Akoll & Mwanja, 2012). Furthermore, the aquaculture industry was not well-established and bacterial diseases, including those which meet the World Organization for Animal Health (OIE) notifiable criteria, were rare. Therefore, it is our opinion that the MLF at a high level and District Veterinary Officers at the local government level should strive to set guidelines and procedures for the surveillance of existing and emerging fish diseases. The guidelines should cover: sample size and sampling, tests, and test procedures, as fish surveillance differs markedly from that of terrestrial animals. In addition, guidelines should adhere to the Guideline for Aquatic Animal Health surveillance established by OIE. Furthermore, institutions such as Universities, Livestock Training Agencies, Tanzania Livestock Research Institute, Tanzania Fisheries Research Institute (TAFIRI), and the National Fisheries

Training Institutes (NFTI) are encouraged to conduct passive surveillance.

This is important because it will assist in disease documentation, monitoring, and controlling diseases at a level where it can be economically tolerated (Hastein, Hellstrom, Jonsson, Olesen, & Pärnänen, 2001). Several countries where aquaculture is intensively practiced have developed their own surveillance systems to monitor nationally prevalent fish diseases in addition to those diseases listed by the Aquatic Animal Health Code (OIE, 2018a). Mainland Tanzania should, therefore, perform a census to establish which bacterial fish diseases are of particular economic and food security concern in extensive and intensive aquaculture in the future.

Mainland Tanzania had several reasons contributed to the dormancy of surveillance of fish diseases, including: (1) a lack of policy that strengthens the aquaculture industry; (2) inadequate funds to carry out fish disease research and implement a surveillance system; (3) little expertise in fish disease diagnosis and treatment; and (4) a strong aquaculture regulatory framework. Most of these challenges have been addressed. The National Fisheries Policy of 2015 and the initiative to develop the Aquaculture Development Act, which is in the final stage, are among them.

3.5. Shortage of fish disease diagnostic facilities and sparse utilization of advanced diagnostic methods

Despite the fact that fish disease detection and diagnosis can be done in any veterinary based laboratory, creating specialized fish diagnostic laboratories that are recognized and accredited by the national and OIE are important to have in the future. Currently, diagnoses are performed by universities and public research organisations which utilise a research methodology. This would cause a challenge if proper communications are not made, especially regarding notable diseases. We think necessary efforts are needed to establish these fish disease diagnostic facilities in the country, especially when the focus is to move to a sustainable commercial aquaculture.

The methods which have been used in carry out the diagnosis of most fish diseases are those which are categorized as level I and II diagnostic tools by OIE, including: observation of fish and environment, clinical examination, and gross pathology. They are important, especially in presumptive diagnoses, and farmers should be well-trained on these simple methods to identify diseases once they occur in their farms before further diagnoses take place. Under intensive aquaculture conditions, early detection of bacterial pathogen from carrier fish is very important for effective fish disease control. Thus, to detect pathogen-carrying fish, a cost effective, sensitive, and specific system is required for surveillance and monitoring fish populations. Detection and characterization of the etiological agent using biotechnological based tools is important because most of the bacterial etiological agents which are reported to cause infection have strain diversity, so these tools should be used in combination with other conventional methods (OIE, 2018b) when conducting surveillance in aquaculture. The application of biotechnology in the aquaculture field has been a challenge due to the inadequacy of experts in the field. Substantial numbers of professionals are now available following the creation of a bachelor degree in Molecular Biology and Biotechnology at the University of Dar es Salaam (UDSM) and a degree in Biotechnology and Laboratory Sciences at Sokoine University of Agriculture (SUA). The challenge in capacity has remained because of a lack of biotechnological equipment in existing basic laboratories in the country.

3.6. Failure to employ fish disease treatment and absence of novel control strategy of bacterial diseases in fish culture

It is well-established that treatment of bacterial fish diseases should be done using selected antibiotics recommended for use in aquaculture by the authorized government organization. For example, in the USA, the Food and Drug Administration (FDA) has recommended three antibiotic formulations for use in aquaculture (Serrano, 2004). These antibiotics, which have been adopted from the FAO, are oxytetracycline, florfenicol, and Sulfadimethoxine/ormetoprim (Romero et al., 2012; Serrano, 2004). Fish farmers in Tanzania do not seem to use antibiotics in aquaculture (Shah et al., 2012) because the majority of fish farmers have no prior knowledge of effective bacterial fish disease treatment. However, relatively high Multiple Antimicrobial Resistant (MAR) index values ware observed by Shah et al. (2012) in selected Tanzanian isolates from fish farms, indicating antibiotic contamination of the aquaculture facilities due to integrated fish farming (Mdegela et al., 2011). The responsible use of antimicrobials and other chemicals in aquaculture is of paramount importance because these chemicals pollute the aquatic environment, establish resistance to microorganisms, and remain as residuals in fish. In mainland Tanzania, the proposed Aquaculture Development Act includes a section on the use of drugs, hormones, and antibiotics to avoid these effects. Treatment guidelines should also be put in place for management officers and aquaculturists who are tasked with assisting fish farmers. A combination of proper management practices and antibiotic use needs to be augmented by a novel disease control strategy that assists these fish farmers in the future. The use of simple, autogenous vaccines, based on accurate typing diagnostics and evidence-based definitions of the epidemiological unit for their use, would be a most viable approach in terms of both efficacy and economic feasibility.

4. Success and prospects toward enhanced fresh water farmed fish in Tanzania

Mainland Tanzania has a population of about 50 million people and now depends largely on fish as the source of protein. Due to population growth, wild fish from freshwater and marine capture fisheries are not enough to meet the growing demand for improving food security and household income. The effort which has been made by the government of Tanzania through the Ministry of Livestock and Fisheries Development has started to revolutionize aquaculture. These efforts include the establishment of the National Fisheries Policy in 2015, the Directorate of Aquaculture Division and the proposed Aquaculture Development Act. Universities have been able to build capacity, in terms of human resources, by establishing Bachelor Degrees in Aquaculture at the graduate level at the University of Dar es Salaam (UDSM), Sokoine University of Agriculture (SUA), and the University of Dodoma (UDOM), and a Master's of Science in Health of Aquatic Animal Resources at the postgraduate level at SUA as well (URT, 2016, p. 40). Expansion in the field of aquaculture from small scale, semi-intensive to intensive fish farming will lead to increased occurrences of fish diseases, especially bacterial diseases.

Therefore, reliable measures should be taken towards sustainable aquaculture industry in Tanzania. These measures are hereby highlighted: strengthening collaborative bacterial fish disease research to identify emerging and re-emerging bacterial diseases in fish farms and developing or strengthening fish disease surveillance for monitoring of bacterial diseases in fish farms. Basic control strategies, such as biosecurity measures and proper management practices, should be emphasized through extension services to farmers. Furthermore, the initiative to strive for innovative technologies towards control of these fish diseases should be taken.

5. Conclusion and recommendation

We conclude that the major challenges to sustainable fish farming in Tanzania include, but are not limited to: limited technical knowhow by farmers on pond management practices and fish health management; limited extension services; inadequate funds to carry out fish disease research and implement a surveillance system; little expertise in fish disease diagnosis and treatment by farmers; shortage of disease diagnostic facilities; failure to employ fish disease treatments; and the absence of a novel control strategy for bacterial diseases in fish culture.

Therefore, for minimal disease outbreaks and optimum production, we suggest strengthening of extension services, augmented with on-farm knowledge transfer. Emphasis should be on: pond management practices and fish disease management; the creation of a well-functioning fish disease surveillance system; and strengthening collaborative research on aquaculture between the government, research institutions, and academia. Creating small cooperative fish farmer groups within the Aquaculture Association of Tanzania (AAT) for easy access to information is also recommended.

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Declaration of competing interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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