DOI: 10.1111/fme.12283

REVIEW ARTICLE

WILEY Fisheries Management and Ecology

Cage fish culture in Lake Victoria: A boon or a disaster in waiting?

J. M. Njiru[1] | C. M. Aura[2] | J. K. Okechi[2]

[1]Kenya Marine and Fisheries Research Institute, Mombasa, Kenya

[2]Kenya Marine and Fisheries Research Institute, Kisumu, Kenya

Correspondence
James M. Njiru, Kenya Marine and Fisheries Research Institute, Mombasa, Kenya.
Email: jamnji@gmail.com

Abstract

Fish catches in Lake Victoria have been on the decline while demand for fish has been increasing. Cage culture with >3,000 cages, over 3 million tilapias and valued at US$ 12 million is trying to fill the gap. This study reviews the development of cages and the need to develop a decision support tool for effective management. Existing literature and data on fisheries and cage culture held by the Kenya Marine and Fisheries Research Institute (KMFRI) were used in the analysis. Cage culture is a promising venture that may increase productivity, offer employment and enhance economic well-being. However, site suitability for the installation of cages is poorly regulated with most developments (>45%) located within 200 m of the shoreline that are breeding grounds of fish and conflict with other lake users. Waste feed increases eutrophication, and enhances growth of algae and water hyacinth in the lake. Recent isolated fish kills were attributed to low dissolved oxygen concentrations (<0.64 mg/L), and an increasing occurrence of fish disease are signs of poor management practices among cage farmers. Cage culture may turn into an environmental disaster if not managed well, and there is need for robust policies and increased awareness to reduce environmental impacts.

KEYWORDS
cage culture, conflicts, dissolved oxygen, Kenya, lake, Tilapia

1 | INTRODUCTION

On a global scale, fish production from natural fish stocks has generally stagnated, with most fisheries already fully or overexploited. Aquaculture is the fastest growing animal production sector in the world and is widely believed to be an important way of reducing the widening gap between fish demand and supply (FAO, 2014, 2016). As a result, its growth has been stimulated in many countries to improve livelihoods, but with varying degrees of success (Russell, Grotz, Kriesemer & Pemsl, 2008).

The contribution of sub-Saharan Africa to fish production from aquaculture focuses mostly on the culture of tilapia (Kaliba, Ngugi, Mackambo & Quagrainie, 2007). Tilapia is the preferred culture species due to its fast growth, resistance to disease and its ability to withstand low dissolved oxygen (DO) levels (Fitzsimmons, 2016). Globally, tilapia production from aquaculture has escalated in recent decades, increasing from 28,000 t in 1970 to 1.2 million tonnes in 2000, more than 2.5 million tonnes in 2007 (FishStat, 2009) and 4.5 million tonnes in 2012 (FAO, 2014). In Kenya, like many other countries of the world, declining fish catches from Lake Victoria combined with a growing demand for protein has led to cage fish farms being developed to improve fish production. Currently, Kenya lies fourth in terms of the level of aquaculture production in Africa, after Egypt, Nigeria and South Africa (FAO, 2016; Fitzsimmons, 2016).

The Kenyan aquaculture industry spans freshwater and marine systems (Munguti, Kim & Ogello, 2014), with freshwater aquaculture showing significant growth over the last decade, while the mariculture sector has been developing more slowly. The aquaculture systems that are most commonly used in Kenya include earthen and lined ponds, dams and tanks. However, cage culture has great potential for boosting fish production in Lake Victoria (Aura et al., 2017).

The use of cages to hold and transport fish is not new; the practice can be traced back to China where it began about two centuries ago (Pillay & Kutty, 2005). However, the more commercial approach to cage culture used today was pioneered in Norway in the 1970s for salmon farming (Tacon & Halwart, 2007). Cage fish culture then expanded throughout the world, with the major producers now being China, Norway, Chile, Japan, Vietnam, Canada, Turkey, Greece, Indonesia and the Philippines (El-Sayed, 2006; Tacon & Halwart, 2007).

In Africa, cage culture began in the 1970s, with a few countries such as Côte d'Ivoire, Ghana, Malawi, Uganda and Zimbabwe recording high levels of productivity each year (Halwart & Moehl, 2006). Most cage culture in Africa is focused on tilapia, which are primarily destined for European and United States (US) markets where they fetch premium prices (Rana & Telfer, 2006). In Lake Victoria, approaches to the development of the cage fish farming industry vary from country to country. For example, in Uganda, Source of Nile (SON) aquaculture has been using cage culture to farm tilapia for many years (Halwart & Moehl, 2006) whereas, in Tanzania, only experimental trials have been allowed in the lake so far, due to concerns about adverse environmental impacts (Kashindye et al., 2015).

On the Kenyan side of Lake Victoria, cage culture dates back to about 2005, when Dominion group of companies (US) started trials around the Yala Swamp at the mouth of the River Nzoia. In 2007, a project funded by the European Union (EU) initiated cage fish culture in small water bodies within the Lake Victoria Basin (Munguti, Kim et al., 2014). By 2008, cage culture trials on the beaches of Lake Victoria (e.g. Dunga) were being undertaken by the Fisheries Cooperative Societies under the Beach Management Unit (BMUs) (Munguti, Kim et al., 2014). These trials consisted of small cages measuring 3.4 to 8 m^3 and used Nile tilapia *Oreochromis niloticus* (L.) and indigenous Victoria tilapia (*Oreochromis esculentus* (Graham). The BMU trials on the beaches were aborted prematurely due to the destruction of the cages by water hyacinth, the use of low-quality netting material being damaged on the rocky substratum and a lack of robust information on cage culture. However, there was

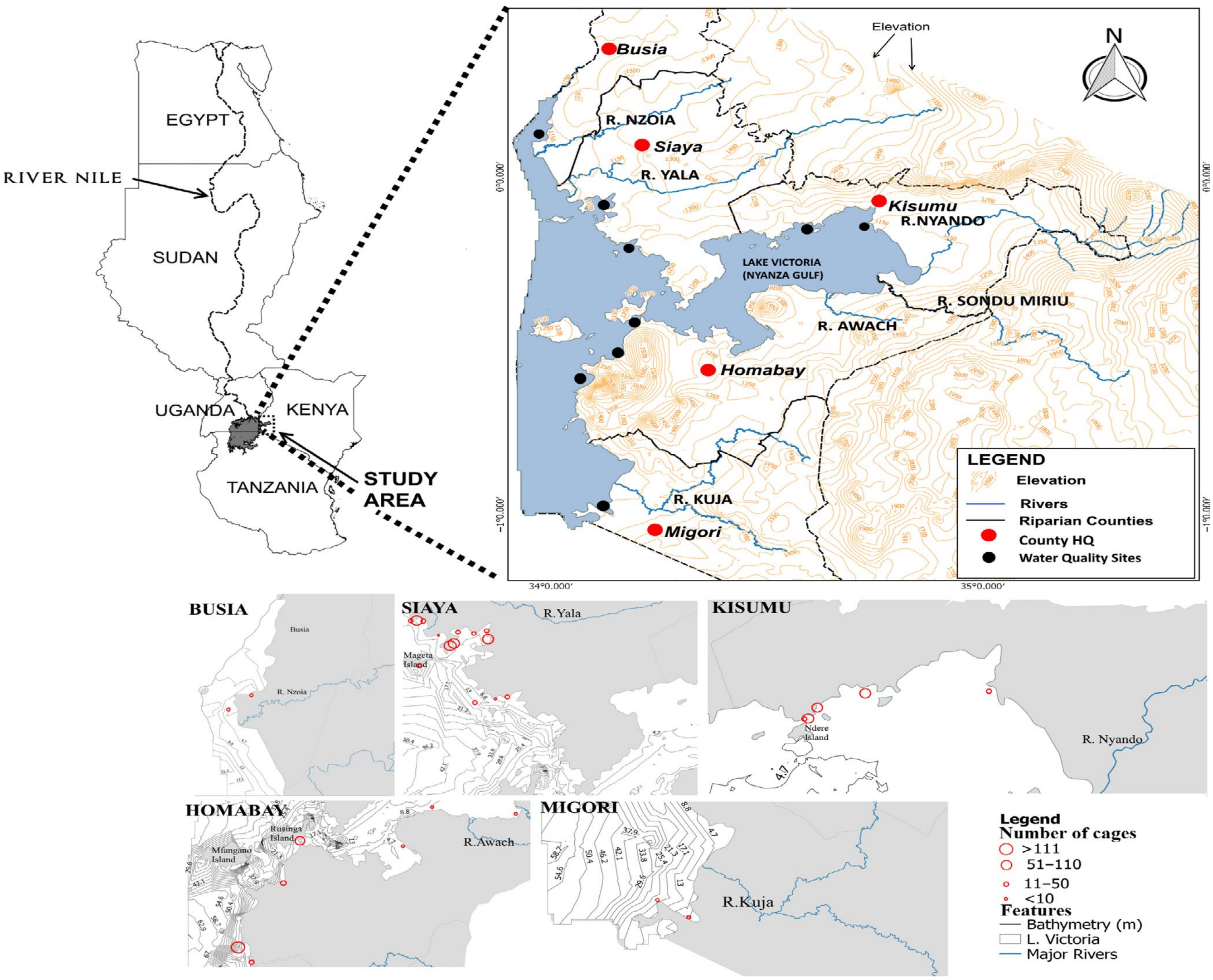

FIGURE 1 Riparian counties of Lake Victoria, Kenya, showing number and locations of fish culture cages

TABLE 1 Summary cage culture assessment in Lake Victoria, Kenya, based on findings in 2016 and 2017

Attributes	2016 findings	2017 findings	Comments
Number of cages	1,663 cages; 39 establishments	3,398 cages; 43 establishments	Cages increasing
Ownership	Individual 24; Group 15	Individual 27; Group 16	Ownership increasing
Gender of owner	Male 35; Female 4	Male 36; Female 7	Male dominated
Dominant age	36–45 = 29%	36–45 = 29%	Middle age dominated
Dominant educational level	Secondary 44%	Secondary 44%	Literate farmers
Mean household monthly income	2,800 US$ per month per farmer	2,000 US$ per month per farmer	Important for development of blue economy
Dimensions of most cages	2.0 × 2.0 × 2.0 m (*n* = 1031; 62%)	2.0 × 2.0 × 2.0 m (*n* = 1196; 35%)	Because cheap and easy to instal in shallow areas
Production (highest in Siaya County)	(*n* = 20; 51%), a total of 1,343 cages	(*n* = 21; 83.8%), a total of 2,847 cages	Lower water hyacinth coverage and prominent history of cages
Number of cages sited at 4-8 m water depth	30 cages (76%)	3,058 cages (90%)	Because cheap and easy to instal in shallow areas, though close to anthropogenic influences
Average stocking density	359 fingerlings/m^3	350 fingerlings/m^3	High stocking levels
Farmers unsure of feed type used	12%	10%	Low-quality feed is detrimental to water quality
Mention of disease occurrence	20 (51%) of establishments	26 (49%) of establishments	About half affected
Common disease type and occurrence	Fin rot mentioned by 11 (28%) of farmers	Fin rot mentioned by 15 (28%) of farmers	Fungal infection dominant
Main challenge	Lack of quality inputs	Lack of quality inputs	Need for increased investment.
Mean dissolved oxygen levels in cages	2.58 mg/L	2.24 mg/L	Declining dissolved oxygen trend
Ammonia concentrations in cages	0.14 mg/L	0.2 mg/L	Worrying toxic trend.
Nutrients (total nitrogen and total phosphorus)	Higher inshore than offshore	Higher inshore than offshore	Likely due to the effect of feeding.

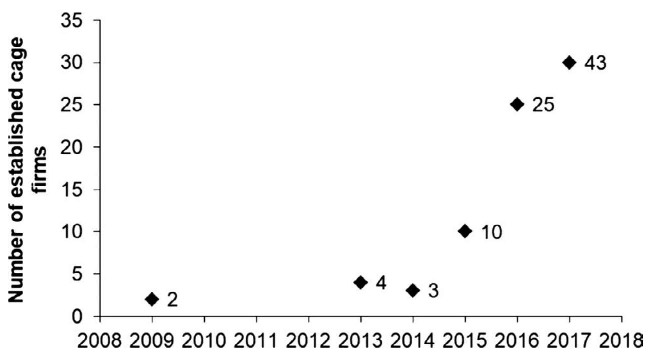

FIGURE 2 Development of the cage culture industry in Lake Victoria, Kenya

a resurgence of interest in cage culture in the lake in 2013, especially at Dunga and Anyanga beaches in Kisumu and Siaya counties, respectively (Guda T., pers. comm.). Since then, cages have spread across the five riparian counties along the Kenya side of Lake Victoria (Figure 1) with about 43 fisheries businesses installing over 3,000 cages and stocking them with >3 million individual tilapia (Figure 2).

This study combines existing literature and cage culture survey data with information from Kenya Marine and Fisheries Research Institute (KMFRI) to review the pros and cons of cage culture to provide evidence that supports effective decision making that is based on ascertaining the relationship between stakeholders, fisheries and the health of the lake ecosystem.

2 | ADVANTAGES AND DISADVANTAGES OF CAGE CULTURE IN LAKE VICTORIA

The current status of cage culture in Lake Victoria, Kenya was mapped and assessed in October – December 2016 and May – July 2017 using geographical information system (GIS), standard water quality monitoring procedures (APHA, 2005), and stakeholder questionnaires and interviews (Table 1) and the benefits and issues found are highlighted below.

3 | BRIDGING THE GAP BETWEEN SUPPLY AND DEMAND FOR FISH

The number of fish landed from Lake Victoria has been declining, while demand has been increasing (Njiru et al., 2014). In particular, demand for protein from fish for human consumption has been increasing due to a rapidly growing population (>3% annually), increasing levels of affluence, and the expansion of urban areas around the lake basin. There has also been an increase in demand for fish protein for both livestock and fish feeds (Munguti, Musa et al., 2014). Worldwide it has been predicted that fish consumption in developing countries will increase by 57%, from 62.7 million tonnes in 1997 to 98.6 million tonnes by 2020 (Halwart, Soto & Arthur, 2007). The increasing number of cages in Lake Victoria is a clear testimony of efforts to meet this increasing demand for fish, however, such rapid expansion of the cage fish farming industry could also be putting more pressure on the environment and existing capture fisheries (Table 1).

4 | GROWING THE BLUE ECONOMY

Cage culture is a profitable aquaculture system in many parts of the world, including Europe, North America, Latin America and Asia (Halwart & Moehl, 2006), and it has huge potential to support economic growth around Lake Victoria if managed carefully. In Kenya, the highest capture of wild tilapia ever recorded was 28,890 t/year, mainly from Lake Victoria, while aquaculture culture attained 30,000 t/year during the Economic Stimulus Program, ESP (FAO, 2014; Munguti, Kim et al., 2014). Land-based aquaculture production was valued at US$ 21 million (Nyonje, Charo-Karisa, Macharia & Mbugua, 2011), with a similar value being estimated for cage culture production. With the 4,000 cages now in the lake and a production rate of 12 million kg of fish per cycle (about 8 months), each harvest is currently worth more than US$ 12 million, and this is expected to increase dramatically as more fish farmers join the industry. This equates to a net income per establishment of about US$ 2,000–2,800 per month.

Cage culture also provides an opportunity to increase employment in the entire lake basin. For example, experienced fishers who are leaving the overfished commercial fishery can be absorbed by the cage farming industry, as has happened in other areas of the world (Masser & Bridger, 2007). These ex-wild fish harvesters represent a highly trained workforce with extensive knowledge of the lake, boat handling techniques, the repair and maintenance of nets, fish harvesting and quality control, which aquaculture companies can easily adapt to their own operations. These former wild fishers would require only some basic training in cage culture husbandry to become fully trained members of the workforce. So, cage farming could provide an excellent opportunity for riparian communities that presentlyrely upon over-harvested commercial fisheries to engage in gainful livelihoods. However, cage culture remains a male-dominated activity, with the majority of owners being aged between 36 and 45 years (Aura et al., 2017). As a result, this middle-level age group is the major beneficiary of cage culture in Lake Victoria. Other groups, such as women and youths, were not assessed but they were often employed in the management of culture systems and marketing of fish. By contrast, a small number of female entrepreneurs (4–7) were found to have founded their own fish culture businesses.

Expansion of cage culture farming presents a lucrative opportunity for the development of the seed and feed sectors, to satisfy increasing demand. It could also promote growth in other sectors of the economy, such as transport, accommodation, tourism and the retail industry. Cage farming investment costs are low per unit of production in comparison with other industries. It also provides more flexibility and higher levels of profit than land-based aquaculture system, because it is easy to relocate, uses existing water bodies, and is more attractive to investors (El-Sayed, 2006).

5 | OPTIMISING THE GROWTH RATE OF CULTURED FISH

Due to better water quality compared with other culture methods, fingerlings grown in lakes tend to have superior growth performance. Cage culture farmers use an average stocking density of 350–359 fingerlings/m^3 (Table 1), with the current stocking density used in the Kenyan portion of Lake Victoria being classified as Low Volume High Density (LVHD) (Musa, S., pers. comm.). Increasing the stocking density creates problems for the fish in terms of overcrowding and a lack of adequate resources. Studies have found that fingerlings stocked at 20–40 g in fish cages attain a market size of 700 g within 4 months, whereas those reared in ponds (even with supplemental feeding) take 6 months to increase in weight from 50 g to 500 g (Diana, Lin & Yi, 1996). Furthermore, tilapia raised in ponds (even with fertilisation and inputs of cheap feed) usually grow more slowly and produce lower yields (<1 kg/m^3 of water) than those reared in cages (20 kg/m^3 of water). In cages, it is also possible to have two cycles of growth per year compared to one in ponds, thereby optimally utilising the water. In Lake Victoria, there are indications that, even if the cycle is about 8 months, the size of fish currently obtained from cages (300 g) is greater than those from most pond culture systems (250 g) when grown over the same period of time. It has been suggested that the duration of a culture cycle will decrease as farmers become more conversant with the process of cage farming and the availability of quality feed and seed.

Interviews among cage culture farmers in Lake Victoria showed that most have no idea of what the ideal stocking density for their systems is. Most of the cages were 2 × 2 × 2 m and located in a rural landscape (Figure 3a,b) (Aura et al., 2017) that had poor access roads and was mainly inhabited by people with low incomes, some of whom were employees of the farmers. In some cases, farmers stocked fish in their cages up to a density of 560 fish/m^3, a density that was far in excess of the recommended density (50–100/m^3). Schmittou, Cremer and Jian (1998) recommended a minimum stocking density of 80 fish/m^3 for tilapia fingerlings with an average weight of 15 g.

6 | MEETING THE DEMAND FOR LIMITED SUPPLIES OF GOOD QUALITY FINGERLINGS AND FEED

The explosion of cage culture in Lake Victoria has exacerbated the already existing problems of meeting demand for good quality fingerlings and feed in Kenya. There is also a lack of appropriately sized

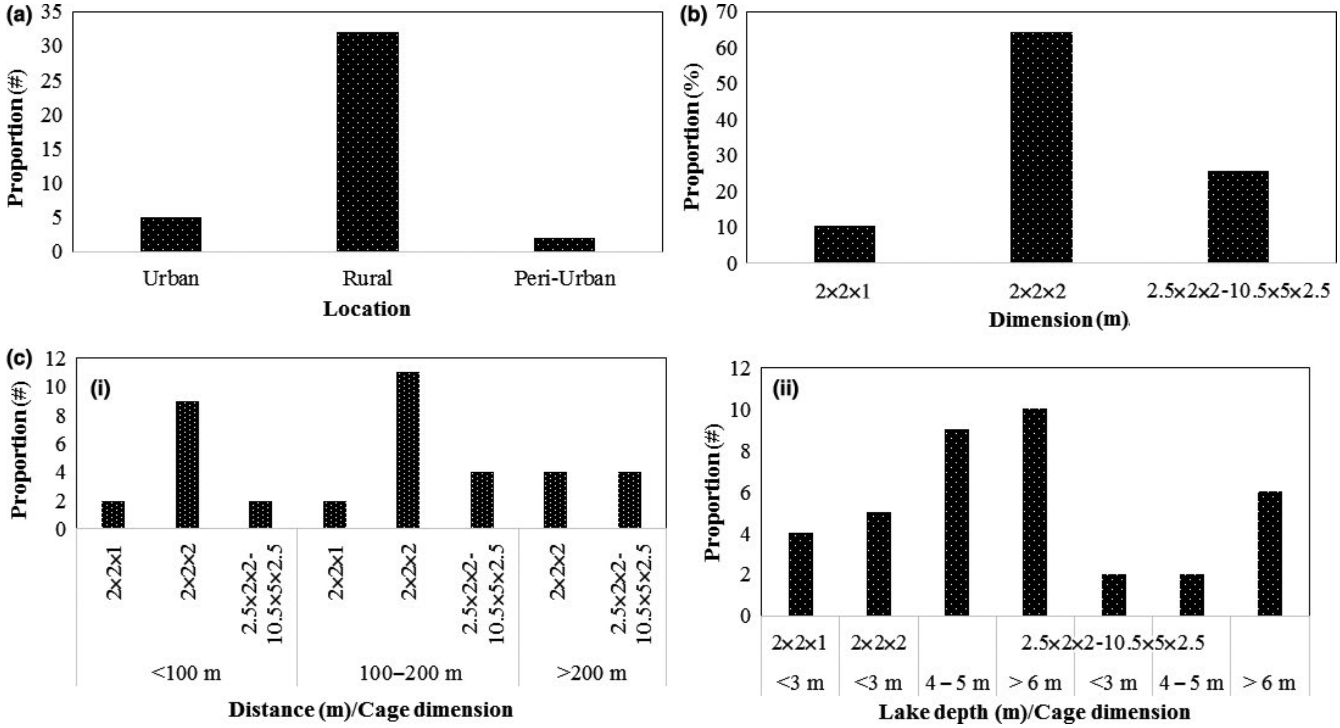

FIGURE 3 Selected characteristics of cage culture sites in Lake Victoria, Kenya, January 2017: (a) type of location, (b) dimensions of cages (m), dimensions of cages (m) in relation to (c, i) distance of cage site from shoreline (m), and (c, ii) lake depth (m) at cage site

tilapia to stock the cages because the hatcheries prefer to produce smaller sized fish, which optimise the economic benefit of production (Charro-Karisa, Munguti, Waidbacher, Liti & Zollitsch, 2010). In Kenya, tilapia suitable for cage culture range between 20 g and 50 g and fetch a local price of US$ 0.05–0.1 each, with smaller tilapia fingerlings (1–5 g) being sold from US$ 0.03 each. This demonstrates that the extra effort and cost involved in rearing larger fingerlings does not translate into monetary gain for the hatchery, thus discouraging producers from growing seed fish to larger sizes. Because supplies from hatcheries have not been sufficient to meet demand, farmers have resorted to sourcing fingerlings from other farmers or from the wild where their quality cannot be guaranteed.

Farmers also formulated their own feed without proper technical knowledge on how this should be performed. So, the feed lacks the essential nutrients for optimum growth, such as protein, carbohydrates, fats, vitamins and minerals. This problem was exacerbated by a lack of suitable storage facilities. This led to supplies of feed being exposed to heat and moisture that, in turn, led to nutrient deterioration. The outcome of these problems was inbred stock, insufficiently supplied with nutrients, leading to poor growth performance and low yields. As a result, fish farming has been abandoned in several areas.

For cage culture to emerge as a benefit to Kenya, the government research and extension wing led by KMFRI and the Kenya Fisheries Service (KeFS), respectively, should be in the forefront of assisting farmers to identify suppliers of good quality seed. Also, KeFS should enhance already existing guidelines on seed production to help hatchery managers and government agencies maintain high-quality products. Additionally, KMFRI should provide information on emerging issues in fish seed and feed.

In collaboration, KMFRI and KeFS should set up gene banks at the national level to function as certified brood stock management and quality seed supply centres. At the local level, satellite hatcheries or seed depositories should be established to function as seed multiplication or collection stations. These centres could also serve as transitional seed-banks, where, before distribution to cage operators, fingerlings are deposited for conditioning and treatment prior to stocking in the cages to minimize post-stocking mortality and losses. This arrangement would give fish farmers easy access to quality seed.

Floating feeds are often recommended for feeding tilapia because they are easier for the fish to eat than sinking pellets, which often end up as waste. This waste then leads to nutrient enrichment of the lake, enhancing water hyacinth and promoting algal blooms. To reduce lake pollution, extruded free-floating feeds should be used instead of sinking feeds. Furthermore, the government of Kenya has tax-exempted imported fish feed ingredients to spur fish feed production. There is also a concerted effort by the government to have farmers, feed suppliers, research institution (KMFRI), fisheries management sector (KeFS) and academia (universities) to work together to improve quality of feed and seed.

7 | CAGE CULTURE SITING

Unregulated growth of fish cages in Lake Victoria poses great risk to the natural environment. Currently, the installation of cages is not regulated and investors can introduce cages into any part of the lake without consulting the community or the state departments that are responsible for regulating the fishery. This situation is bound to generate conflict with other lake stakeholders, especially fishers and transporters who use the same limited part of the lake. Spatial analysis of cage farm location has shown that 76% of cage establishments in Lake Victoria are located in the gulf within 200 m of the shoreline, and in relatively shallow water (4–8 m depth), despite some of these areas being demarcated as nursery and breeding zones for the wild fish population (Table 1; Figure 3c) (KMFRI, 2016). This is mainly because most farmers prefer such zones because they provide ease of access opportunities for close supervision, and because they are sheltered from potentially damaging winds and currents. However, it has been shown that the location of these cages in the water body may interfere with water circulation (Aura et al., 2017). Additionally, the Kenyan part of the lake has 14,000 fishers, 44,000 fishing boats, 230,000 gillnets, 900 boat seines, 600 beach seines and 600 transport boats (Frame survey, 2016). This high level of fisheries-related activities makes the Kenyan part of the lake very crowded, leaving very limited space for setting up cages. This high level of competition for resources is compounded by water hyacinth, which at times can cover about 1% of the shallow part of lake for several months at a time. It is expected that if the situation is not properly managed, competition for space will soon escalated into serious conflicts among lake users. Classical examples of such conflicts have been witnessed in Asia (Halwart et al., 2007). For example, the development of pen farming of milkfish in Laguna De Bay, Philippines, reduced fishers' access to traditional fishing grounds thereby leading to conflicts (Marte, Cruz & Flores, 2000). Unless development is controlled through lake-zonation, that is by dividing the lake into zones based on suitability of use, these conflicts could threaten the livelihoods of millions of the poorest in fishing communities that depend on these resources (Murshed-e-Jahan, Salayo & Kanagaratnam, 2009).

The investors in cage farming seem to be ahead of the government agencies that are supposed to regulate (State Department of Fisheries and Blue Economy, SDF & BE) and do research (KMFRI) in the lake. There are no policies or guidelines on cage farming in Lake Victoria, so the venture lacks proper guidance (Charro-Karisa et al., 2010). Currently, there are no agreed protocols on species introduced or mitigation plans to address any of the adverse effects of cage farming. This lack of guidance on cage farming is very likely to be counter-productive in the long run (Kampayana, Nguyen & Le, 2016). Also, without proper policies and guidance to support their development, and with little scientific evidence to support the sustainable development of cage fish farms in the lake, environmental groups may soon start to discredit the cage farming industry and win a lot of public sympathy (Masser & Bridger, 2007).

Lake Victoria's Nyanza Gulf is currently classified as hyper-eutrophic (Kolding, Van Zwieten, Mkumbo, Silsbe & Hecky, 2009), and unplanned cage development and fish feeding is bound to exacerbate this problem by introducing more nutrient pollution to the lake. Therefore, caution should be taken when authorising cage culture in the lake so as not to compromise the water quality, which is already degraded, and impair the ability of the lake to provide benefits, sustainably, to the communities whose livelihood depend on it. KMFRI has already developed guidelines and suitability maps on where cages can be sited. These have been shared with the relevant authorities. It has been suggested that permits for cage culture should be based on these suitability maps. When siting cages, it also essential to assess the likely positive and negative impacts on the ecosystem (Grøttum & Beveridge, 2007). Siting must also take into account the need to reduce predation, poaching and destruction by animals, and the need to control access and reduce poaching risks (including through the use of electronic security systems). Community engagement and community surveillance are key to success of cage culture because they ensure ownership of, and community responsibility for, the projects (Charro-Karisa et al., 2010).

8 | IMPACT ON THE LAKE ECOSYSTEM

Cage operators are expected to clean cage nets to reduce clogging and fouling and to engage in proper management practices to enhance water quality and performance of fish (Shoko, Limbu, Mrosso & Mgaya, 2014). Lack of strict adherence to this code of contact has resulted in fish kills, low dissolved oxygen (DO) levels and the spread of disease. In water quality surveys using standard methods (APHA, 2005), DO ranged between 2.24 and 2.58 mg/L in the water column around the cages, while inside the cages levels were as low as 0.64 mg/L (KMFRI, 2016). This low DO within the cages has been attributed to poor water circulation across the walls of the cages as a result of nets becoming clogged by algae and the decomposing remains of feed. Another reason may have been the reduction of water movement caused by the presence of fish in cages. The conditions created within the cages are not suitable for fish that are known to thrive best at DO levels >3 mg/L (Aura et al., 2017).

Ammonia around the cages ranged between 0.14 and 0.2 mg/L. Increase in ammonia near the cages was attributed to the protein in uneaten food and fish waste that had been broken down into ammonia and nitrite. Ammonia can be extremely toxic to fish, with toxic levels of unionised ammonia ranging from 0.6 to 2.0 mg/L in the case of tilapia. Unionised ammonia begins to depress appetite of this fish species at concentrations as low as 0.08 mg/L. The first mortalities from prolonged exposure (several weeks) begin at unionised ammonia concentrations as low as 0.2 mg/L, especially among fry and juveniles in water with low DO. Also, fish exposed to low levels of ammonia over time are more susceptible to bacterial infections and have poor growth. Recorded fish kills equivalent to about US$ 4,300 occurred in the cages in Lake Victoria in 2016; this was attributed to low dissolved oxygen concentrations, although a combined effect, involving ammonia and oxygen, is possible.

9 | STRESS, DISEASES AND FISH KILLS

Intensification of any intensively managed biological production, such as aquaculture, will inevitably result in problems, especially in relation to infectious diseases. In this study, half of cage establishments reported diseases and parasites occurring in their fish. The unhealthy conditions observed were mainly fin rot, which was attributed to high stocking density, poor water quality and bad management practices.

KMFRI Aquaculture researchers investigated the possible causes of fish kills at Anyanga and Nyenye-Got beaches in Siaya County where there are 155 and 600 cages, respectively, each 8 m^3 in size (KMFRI, 2016). The study found that there was poor water circulation across the walls of the cages due to clogging by algae and the remains of feeds. This resulted in lower DO concentrations within the cages compared to the lake. For example, at Nyenye-Got, a DO concentration of 4.5 mg/L was measured at the control site (about 300 m from the cages) and there was a very a large DO variation ($p < 0.05$; $F = 5.25$) between inside and outside of the cages. Dissolved oxygen concentrations of 2.0 mg/L were recorded in the water column around the cages but average levels of < 0.64 mg/L inside the cages. This is of concern give a DO of 4.0 mg/L gives optimal growth and performance in tilapia culture (Hecky et al., 1994). The economic loss of these fish kills amounted to US$ 4,300 and US$ 570,000 at Anyanga and Nyenye-Got beaches, respectively.

Fish kills in Nyenye-Got area could have been a result of low DO concentrations in the cages and around the cages due to periodic upwelling of hypoxic water. An interview with the local community and the cage owners indicated that the fish kills were not restricted to cage fish, but also affected the wild fish and other aquatic biota (KMFRI, 2016) across the whole of Goye Bay. This could have been due to normal annual stratification, which creates vertical mixing that lifts a layer of water with low DO concentrations to the surface (Guya, 2013). The high stocking densities of 250 fish/m^3 in the cages probably restricted movement of the cage fish, increasing competition for DO and, thus, exacerbating the kills. This hypothesis is supported by the few cages having low stocking density (63 fish/m^3) experiencing only partial fish mortality.

Cage culture is an open system that allows exchange of diseases and pathogens between cultured and native fish. With an upsurge in new diseases in farmed fish, the Government of Kenya needs to apply more stringent control measures to ensure food biosafety in aquatic animals. For example, any introduced fish should be quality controlled to ensure that fingerlings are in good health and free from any pathogens that are potentially dangerous to wild fish species. This could be achieved by developing and implementing new policies and guidance on the transfer or import of fingerlings and eggs. Currently, the riparian states of Kenya, Uganda and Tanzania, through the Lake Victoria Organization (LVFO), are in an advance stage of rolling out guidelines on cage culture in Lake Victoria. The guidelines are aimed at helping hatchery managers and government agencies to maintain high quality operating procedures and products in cage culture. The guidelines, which have built on experiences from other parts of the world, have been adapted to suit the local environment.

There is also need for large-scale infrastructure to control and monitor fish movement to reduce entry and the spread of disease. In this regard, the Government of Kenya, assisted by the Government of Spain, has enhanced facilities for doing this by establishing state-of-the-art laboratories in Kisumu, Nairobi and Mombasa. The facilities, which are dedicated to monitoring fish quality and related issues, will provide a basis for monitoring emerging fish diseases such as tilapia lake virus (TiLV) and other pathogens. The overall aim is to promote good farm husbandry to reduce outbreak of disease caused by overstocking, stress and water quality issues.

10 | CONCLUSIONS AND RECOMMENDATIONS

The main advantage of cage farming in Lake Victoria is that it offers the opportunity to take up cage farming to improve livelihoods, especially to ex-commercial fishers and lakeside communities. Cage farming provides employment, increased income and a supply of fish protein. It also reduces pressure on native fish by diverting the harvesting of fish from wild stocks to farmed fish. The current activities in cage farming in Lake Victoria are in their initial stages, but early results suggest that cage culture in Lake Victoria is a promising blue growth venture. However, for cage farming to be a success, an effective policy framework for lake-zonation is needed to ensure that all stakeholders use the lake without impinging on the development opportunities of others.

Furthermore, with lack of proper policy guidelines and management practices in place, cage farming is likely to be an environmental disaster. It is believed that cage culture in Lake Victoria will expand in an unregulated way causing potential conflicts of interest in areas that are also used by stakeholders such as fishers, transporters, tourists, domestic and industrial water abstractors. To avoid such conflicts, mapping and zoning of the lake for various lake-based activities is required.

With the growth of cage farming in the lake and the potential for conflict with other users, effective communication among parties will be key to averting such problems. Conflict could be minimised by cage culture investors involving the public at all stages of their planning and development processes so that concerns can be raised. Furthermore, an environmental impact assessment involving stakeholders may also help to alleviate some of these challenges. Cage farmers need to be more pro-active in engaging local communities. For example, farmers could form discussion groups and management committees that would monitor and evaluate the systems and provide strong links to other stakeholders.

Addressing issues relating to the quality of seed and feed, stocking densities, the size, sex and biology of fish, fish tolerance to various aspects of water quality and the siting of fish cages within the water body are critical to the successful development and implementation of cage culture in Lake Victoria. Training to provide evidence-based guidance on good practice should be provided to cage operators and extension officers in relation to cage design, construction and maintenance, seed production and handling, optimum stocking densities, fish disease and control, monitoring of fish growth performance, harvesting and post-harvest techniques, economic performances and environmental assessment and management. To partially meet this need, KMFRI has recently published manuals and brochures on best cage culture management practices that are readily available to farmers. KMFRI has also posted technical staff to cage farming areas to help the farmers. However, there is also a need for KMFRI, in conjunction with other stakeholders, such as KeFS and the universities, to develop tailor-made training curricula.

Support for the sustainable development of aquaculture should also be sought from the private sector and Non-Governmental Organizations (NGOs). In East Africa, bodies like the Association for Strengthening Agricultural Research in East and Central Africa (ASARECA) and Farm Africa could be instrumental in ensuring the success of cage culture in the region.

ACKNOWLEDGMENTS

We wish to acknowledge KMFRI for financial support. Dr. Linda May from Centre of Ecology and Hydrology, UK helped in English editing.

REFERENCES

APHA (2005). *American Public Health Association Standard Methods for the examination of water and wastewater*, 21st edn. Washington, DC: APHA-AWWA-WEF. ISBN 0875530478.

Aura, M. C., Musa, S., Yongo, E., Okechi, J., Njiru, J. M., Ogari, Z., … Abwao, J. (2017). Towards balancing lake use and culture fisheries off Lake Victoria beaches, Kenya: Mapping and socio-economic assessment of cage culture. *Aquaculture Research*, *00*, 1–14. https://doi.org/10.1111/are.13484

Charro-Karisa, H., Munguti, J. M., Waidbacher, H., Liti, D., & Zollitsch, W. (2010). *Low-input cage culture: towards food security and livelihood improvement in rural Kenya*. EC FP7 Project, SARNISSA. Retrieved from www.sarnissa.org/tiki-download_file.php?fileId=228.

Diana, J. S., Lin, C. K., & Yi, Y. (1996). Timing of supplemental feeding for tilapia production. *Journal of the World Aquaculture Society*, *27*(4), 410–419. https://doi.org/10.1111/j.1749-7345.1996.tb00625.x

El-Sayed, A. F. M. (2006). *Tilapia culture*. Wallingford, GB, England: CABI Publishing.

FAO (2014). *The state of world fisheries and aquaculture 2014*. Rome, Italy: FAO Fisheries Department, Fishery Information, Data and Statistics Unit.

FAO (2016). *The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all* (pp. 200). Rome, Italy: FAO.

FishStat (2009). Retrieved from www.fao.org/fishery/statistics/en. Accessed 17th November 2016.

Fitzsimmons, K. (2016). *Supply and demand in global tilapia markets*, *2015*. Aquaculture 2016, Las Vegas, Nevada: pp. 23–26 Feb 2016. Retrieved from https://www.was.org/documents/Meeting Presentations/AQ2016/AQ2016_0005.pdf.

Frame survey. (2016). *Lake Victoria (Kenya) biennial fisheries frame survey 2016 national report*. Nairobi, Kenya: State Department of Fisheries and Blue Economy, 16 pp.

Grøttum, J. A., & Beveridge, M. (2007). A review of cage aquaculture: Northern Europe. In M. Halwart, D. Soto & J. R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview* (pp. 126–154). Rome, Italy: FAO. FAO Fisheries Technical Paper. No. 498.. 241 pp.

Guya, F. J. (2013). Bioavailability of particle-associated nutrients as affected by internal regeneration processes in the Nyanza Gulf region of Lake Victoria. *Lakes and Reservoirs: Research and Management*, *18*, 1–15.

M. Halwart & J. E. Moehl (Eds) (2006). *FAO Regional technical expert workshop on cage in Africa*, *Entebbe*, *Uganda*, *20–23 October 2004*. Rome, Italy: FAO. FAO Fisheries Proceedings No. 6, 113p.

Halwart, M., Soto, D., & & Arthur, J. R. (2007). *Cage aquaculture: regional reviews and global overview*. Rome, Italy: FAO. FAO Fisheries Technical Paper No. 498, 241 pp.

Hecky, R. E., Bugenyi, F. W. B., Ochumba, P. B. O., Talling, J. F., Mugidde, R., Gophen, M., & Kaufman, L. (1994). Deoxygenation of the deep water of Lake Victoria, East Africa. *Limnology and Oceanography*, *39*, 23–36.

Kaliba, A. R., Ngugi, C. C., Mackambo, J., & Quagrainie, K. K. (2007). Economic profitability of Nile tilapia (Oreochromis niloticus L.) production in Kenya. *Aquaculture Research*, *38*, 1129–1136. https://doi.org/10.1111/j.1365-2109.2007.01772.x

Kampayana, F., Nguyen, S. T., & Le, M. H. (2016). Tilapia cage culture in Rwanda: Current status and prospects for future development. *International Journal of Fisheries and Aquatic Studies*, *4*(3), 428–435.

Kashindye, B. B., Nsinda, P., Kayanda, R., Ngupula, G. W., Mashafi, C. A., & Ezekiel, C. N. (2015). Environmental impacts of cage culture in Lake Victoria: The case of Shirati Bay-Sota, Tanzania. *SpringerPlus*, *4*, 475. https://doi.org 10.1186/s40064-015-1241-y

KMFRI. (2016) *Fish kills in cages off beaches in Lake Victoria, Kenya: Imprinting the possible causes*. Technical Report for Kenya Marine and Fisheries Research Institute (KMFRI) Kisumu. 12 pp.

Kolding, J., Van Zwieten, P., Mkumbo, O. C., Silsbe, G., & Hecky, R. (2009). Are the Lake Victoria fisheries threatened by exploitation or eutrophication? Towards an ecosystem based approach to management In G. Bianchi & H. R. Skjoldal (Eds.). *The Ecosystem Approach to Fisheries*, (pp. 309–354). Wallingford, UK: FAO, Rome and CABI International.

Marte, C. L., Cruz, P., & Flores, E. E. C. (2000). Recent Developments in Freshwater and Marine Cage Aquaculture in the Philippines. In I. C. Liao & C. K. Lin (Eds.). *Cage Aquaculture in Asia: Proceedings of the First International Symposium on Cage Aquaculture in Asia* (pp. 83–96). Manila, Philippines: Asian Fisheries Society and World Aquaculture Society – Southeast Asian Chapter, Bangkok, Thailand.

Masser, M. P., & Bridger, C. J. (2007). A review of cage aquaculture: North America. In M. Halwart, D. Soto & J. R. Arthur (eds). *Cage aquaculture – Regional reviews and global overview*, (pp. 102–125). Rome, Italy: FAO. FAO Fisheries Technical Paper No. 498. 2007. 241 pp.

Munguti, J. M., Kim, J. D., & Ogello, E. O. (2014). An overview of Kenyan aquaculture: Current status, challenges, and opportunities for future development. *Journal of Fisheries and Aquatic Science*, *17*(1), 1–11. https://doi.org/10.5657/FAS.2014.0001

Munguti, J. M., Musa, S., Orina, P. S., Kyule, D. N., Opiyo, M. A., Charo-Karisa, H., & Ogello, E. O. (2014). An overview of current status of Kenyan fish feed industry and feed management practices, challenges and opportunities. *International Journal of Fisheries and Aquatic Studies*, *1*(6), 128–137.

Murshed-e-Jahan, K., Salayo, N. D., & Kanagaratnam, U. (2009). Managing fisheries conflicts through communication planning: Experience from inland fisheries of Bangladesh. *Fisheries Research*, *99*(2), 112–122. https://doi.org/10.1016/j.fishres.2009.04.009

Njiru, M., van Knaap, M., Taabu, M. A., Nyamweya, C., Kayanda, R., Mlaponi, E., & Marshall, B. (2014). Management of Lake Victoria fishery: Are we looking for easy solutions? *Aquatic Ecosystem Health Management*, *17*(1), 70–79. https://doi.org/10.1080/14634988.2014.881220

Nyonje, B. M., Charo-Karisa, H., Macharia, S. K., & Mbugua, M. (2011). Aquaculture development in Kenya: Status, potential and challenges, aquaculture development in Kenya towards food security, poverty alleviation and wealth creation. *Samaki News*, *7*(1), 8–11.

Pillay, T. V. R., & Kutty, M. N. (2005). *Aquaculture: Principles and practices*, 2nd edn. (p. 624). Oxford, England: Blackwell Publishing Ltd.

Rana, K., & Telfer, T. (2006). Primary drivers for cage culture and their relevance for Africa cage culture. In M. Halwart & J. E. Moehl (eds). *FAO Regional Technical Expert Workshop on cage culture in Africa, Entebbe, Uganda, 20-23 Oct 2004* (pp. 97–107). Rome, Italy: FAO. FAO Fisheries Proceedings. No 6.

Russell, A., Grotz, P., Kriesemer, S., & Pemsl, D. (2008). *Recommendation domains for pond aquaculture: Country case study: Development and status of freshwater aquaculture in Malawi*. Penang, Malaysia: The WorldFish Center. WorldFish Center Studies & Reviews No. 1869. 52 pp.

Schmittou, H. R., Cremer, M. C., & Jian, Z. (1998). *Principles and practices of high density fish culture in low volume cages* (pp. 88). USA: American Soybean Association.

Shoko, A. P., Limbu, S. M., Mrosso, H. D., & Mgaya, Y. D. (2014). A comparison of diurnal of water quality parameters in Nile tilapia (*Oreochromis niloticus*, Linnaeus, 1758) monoculture and polyculture with African sharp tooth catfish (*Clarias ariepinus*, Burchell, 1822) in earthen ponds. *International Aquatic Research*, *6*, 56. https://doi.org/10.1007/s40071-014-0056-8

Tacon, A. G. J., & Halwart, M. (2007). Cage aquaculture: A global overview. In M. Halwart, D. Soto & J. R. Arthur (eds), *Cage aquaculture: Regional reviews and global overview*(pp 1–6). Rome, Italy: FAO. FAO Fisheries Technical Paper No. 498.

How to cite this article: Njiru JM, Aura CM, Okechi JK. Cage fish culture in Lake Victoria: A boon or a disaster in waiting?. *Fish Manag Ecol*. 2019;26:426–434. https://doi.org/10.1111/fme.12283