ARTICLE IN PRESS

Journal of Great Lakes Research xxx (xxxx) xxx

Contents lists available at ScienceDirect

Journal of Great Lakes Research

journal homepage: www.elsevier.com/locate/ijglr

The extent of cage aquaculture, adherence to best practices and reflections for sustainable aquaculture on African inland waters

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ARTICLE INFO

Article history:
Received 25 February 2019
Accepted 23 August 2019
Available online xxxx
Communicated by Erin Dunlop

Keywords:
Cage aquaculture
Africa
Freshwater
Ecosystem approach to aquaculture

ABSTRACT

Cage aquaculture is expanding on African inland waters and has potential to close the fish supply deficit in the region and provide other social benefits such as employment and income. However, if not appropriately guided and regulated, cage aquaculture could become unsustainable, causing conflicts with other water uses, environmental degradation and economic losses to aquaculture enterprises. To enhance sustainability of cage aquaculture on the African inland waters, we developed an inventory of cage aquaculture installations and used it to investigate the distribution and magnitude of cage aquaculture and adherence to best practices for sustainable aquaculture. Our results show evidence of spatial expansion of cage aquaculture on the African inland waters, of varying magnitude across and within water bodies and partial adherence to best practices. Cage aquaculture was confirmed on 18 water bodies which together share 263 installations with more than 20,000 cages. Lakes Victoria, Kariba, Volta and River Volta host 82.9% of cage aquaculture installations on the African inland waters and are major areas for cage aquaculture. Contrary to best practices, evidence shows cage aquaculture installations entirely or in close proximity to protected areas, in eutrophic and hypertrophic waters, shallow water bodies and sites ($\geq$5 m average depth) and close to the shoreline. Cage aquaculture is qualified as an additional stressor to the African inland waters and because it is expected to continue expanding, adherence to best practices should be promoted for sustainability.

Introduction

Global consumption of fish is increasing, partly due to improved preference of fish as source of high-quality nutrients (Tacon and Metian, 2013). Subsequently, global per capita fish consumption has increased from 9.0 kg per year in 1961 to 20.2 kg in 2015 (FAO, 2018). The challenge, however, is the discrepancy in the global fish consumption with developed countries enjoying higher fish per capita consumption compared to developing countries with low or declining per capita fish consumption (FAO, 2018).

In sub-Saharan Africa, where majority of countries are developing or low-income food-deficit (FAO, 2019), per capita fish consumption is as low as < 2 kg per year in some countries (FAO, 2016). Fish consumption in these countries is low because of inadequate local supplies (FAO, 2018). With these countries having high annual population growth rates, the fish supply deficit could worsen in future. In Uganda for instance, per capita fish consumption is about 8 kg, a level below the 2015 global average of 20.2 kg (FAO, 2018). With a population of about 38.8 million people (UBOS, 2018), Uganda needs about 790,000 tonnes of fish annually for Ugandans to consume fish at the global average level. In addition, the international and regional annual export markets each require about 200,000 tonnes of fish, indicating that Uganda needs an annual fish production of at least 1.18 million tonnes. With an

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https://doi.org/10.1016/j.jglr.2019.09.011
0380-1330/

Please cite this article as: L. Musinguzi, J. Lugya, P. Rwezawula et al., The extent of cage aquaculture, adherence to best practices and reflections for sustainable aquaculture on African inland waters, Journal of Great Lakes Research, https://doi.org/10.1016/j.jglr.2019.09.011

annual production of about 500,000 tonnes (FAO, 2005–2009; UBOS, 2018), comprising of 400,000 tonness from capture fisheries and 100,000 tonnes from aquaculture, Uganda has a fish supply deficit of about 690,000 tonnes.

The fish consumption deficit in sub-Saharan Africa is contributory to the region's poor nutrition status. The region is home to 94.5% of the undernourished people in Africa, with special groups of people such as infants and pregnant women being the most vulnerable (FAO, IFAD & WFP, 2014). Because fish provides high-value proteins superior to those from terrestrial animals, essential amino acids, minerals, trace elements and omega-3 fatty acids (Tacon and Metian, 2013), fish supply is vital in the fight against malnutrition in the region.

The global surge in fish consumption has coincided with a critical development stage for wild fisheries. Global fish production from wild fish stocks has stagnated, with most fisheries fully or over-exploited (Worm et al., 2006; FAO, 2014). Aquaculture is perceived as the only available option for increasing fish production to meet the fish supply deficit. Indeed, aquaculture is now the fastest growing food production system, and its contribution to global fish production is increasing (FAO, 2018). Unfortunately, like per capita consumption, fish production from aquaculture is poor in sub-Saharan Africa and considerable interventions, including adoption of more productive aquaculture systems, are required. Cage aquaculture is being considered to increase fish production in Africa. Known to increase fish production (Gentry et al., 2017), cage aquaculture has interested many fish farmers, reportedly because of its better potential compared to pond-based aquaculture. Attributes of cage aquaculture include higher production per unit volume of water, lower costs of investment and easier routine farm management practices (Beveridge, 1984). As a result, cage aquaculture is developing on African inland waters albeit with limited regulation and restriction.

Poorly planned cage aquaculture industry on African inland waters is a threat to existing uses such as fishing, recreation, and water extraction for domestic and industrial use. To promote sustainable development of cage aquaculture on African inland waters, we created a dataset of cage aquaculture installations on the waters and used it to examine the magnitude of cage aquaculture development and the adherence to best practices during siting of cage aquaculture installations. Good siting, coupled with good management practices can address the potential environmental challenges of cage aquaculture and avoid conflicts with other uses, conforming to Ecosystem Approach to Aquaculture (EAA) (FAO, 2010; Bueno et al., 2013; Aguilar-Manjarrez et al., 2017). Based on observations, we suggest best management practices that should be promoted to ensure that cage aquaculture development on African inland waters is sustainable.

Methods

Data acquisition

Location of cage aquaculture installations and extent of cage aquaculture

Data on locations of cage aquaculture installations on the African inland waters was obtained using three approaches. The first approach involved visual identification of installations from satellite images within Google Earth Engine (GEE). The GEE provides satellite images with enough resolution to identify physical features on land. It has been used to locate marine cage aquaculture installations (Trujillo et al., 2012; Oyinlola et al., 2018). For each installation identified, the GEE place mark tool was used to retrieve location data (latitude and longitude). The identification of cage aquaculture installations through this approach is limited by presence, within GEE, of outdated satellite images in some areas which do not cover installations established after their acquisition dates (Trujillo et al., 2012). This limitation was reduced using two other approaches i.e. ground truthing surveys, and phone interviews.

Data from ground truthing surveys were available for Lake Malawi from Malawi's Department of Fisheries, Kenyan part of Lake Victoria from Kenya Marine and Fisheries Research Institute (KMFRI), Tanzanian part of Lake Victoria from Tanzania Fisheries Research Institute (TAFRI) and lakes Kivu and Muhazi from Rwanda Agriculture Board. Ground truthing was conducted through actual site visits to the cage fish farms, during which data was collected on parameters such as location (latitude and longitude), and number of cages (e.g. Aura et al., 2018). Phone interviews were only conducted in Uganda. These involved contacting focal persons (District Fisheries Officers) who oversee local cage aquaculture development in Uganda to provide information on locations of installations and number of cages. Locations obtained from this approach were geo-referenced within GEE. Cage aquaculture installations from ground truthing and interviews were further validated within GEE. However, unconfirmed installations were also maintained in our dataset as images within GEE are not always updated.

For all installations confirmed in the GEE, we retrieved additional data useful for making inferences on the extent and sustainability of cage aquaculture on the African inland waters. We retrieved data on number of cages at each installation (if not available from the ground truthing datasets and interviews), area covered by cages, and the distance of siting from the shoreline (the distance between the shoreline and the cages). The number of cages was obtained by enumerating the cages at each location, enabled by the high-resolution satellite images. We obtained the area covered by cages using the polygon tool within GEE that measures area of geometric shapes (polygons). The distance between the shoreline and cages was obtained using the line tool that measures distance between two points.

Adherence to best practices during siting of cage aquaculture installations

Our inventory of cage aquaculture installations provided an opportunity to explore gaps between establishment practices of cage aquaculture installations on African inland waters and internationally recognized best practices for sustainable cage aquaculture (Aguilar-Manjarrez et al., 2017). Adherence to best practices makes cage aquaculture sustainable by safeguarding biodiversity and ecosystem services in the holding water body, avoiding conflicts with other uses and optimizing benefits to farmers (FAO, 2010).

We explored the adherence to best practices through the lens of chlorophyll-a (Chl a) as a proxy of nutrients, depth of the holding water body or site of installation, proximity to protected areas and distance of installations from the shoreline. For best practices (e.g. Aguilar-Manjarrez et al., 2017), cage aquaculture installations are expected to avoid areas of excessive nutrients (eutrophic and hypertrophic) to safeguard the farmed fish and avoid further deterioration of water quality. Installations are recommended in water bodies or sites of depth of at least 5 m to ensure proper water exchange within cages, dispersion of wastes and self-revitalization. Placing installations at- least 1 km away from protected areas is considered a safe distance (buffer) to safe guard the protected elements such as habitats and threatened species (Aguilar-Manjarrez et al., 2017). Finally, cages are preferably placed away from the shoreline, a measure to safeguard fragile habitats that characterize these areas and reduce conflicts with other uses.

The Chl a data used was obtained from the ocean color web portal of NASA (https://oceancolor.gsfc.nasa.gov/), which provides near surface concentration of Chl a for water bodies. We retrieved a level-3 product of the Chl a, presenting annual average Chl a concentration for 2017. This data was limited as its geographical extent did not fully cover the surface area of all the water bodies and small water bodies and rivers with cages. Nevertheless, the data were useful for lakes such as Victoria, Kariba, Malawi, and Albert which were satisfactorily represented. The data covered all installations on lakes Malawi and Albert, 83.3% of Lake Kariba installations and 22% of all the installations on Lake Victoria. Data on depth for water bodies were available from HydroLakes (Messager et al., 2016). Depth specific to sites of individual installations was only available for Lake Victoria from the lake's bathymetry map, available from Harvard Dataverse (Hamilton et al., 2016). We used the point sampling tool in QGIS to acquire Chl a concentrations (mg/m^3) and depth values at the individual installations. We obtained data on protected areas from the world database of protected areas (IUCN and UNEP-WCM, 2019). Lake shorelines were inferred from lake boundaries within HydroLakes (Messager et al., 2016).

Data processing and analysis

We developed a georeferenced dataset of cage aquaculture installations on the African inland waters using the location data (Electronic Supplementary Material (ESM) Table S1). The dataset mainly includes data on water body, location, coordinates, country, GEE status (whether confirmed in GEE or not) as well as the number of cages, distance from the shoreline and area under cages mostly for installations confirmed within the GEE. Using the location data and the layer of African inland water bodies extracted from HydroLakes (Messager et al., 2016), we illustrated the spatial distribution of the cage aquaculture installations on the African inland waters. Averages for number of cages per installation and area covered were calculated and used to estimate number of cages and area covered for each water body. This was possible only for water bodies for which information was available on number of cages and area of coverage. For lakes, estimated area under cages was further expressed as a percentage of the total surface area. Distance of installations from the shoreline was summarized using descriptive statistics .

Using a numeric trophic index (Carlson, 1977; Anthony et al., 2016), the Chl a concentration was categorized into hypertrophic, eutrophic, mesotrophic and oligotrophic, enabling the identification of installations occurring in areas that should not be used for cage aquaculture i.e. hypertrophic or eutrophic. Depth data for individual installations from the bathymetry of Lake Victoria was summarized using descriptive statistics. To identify installations entirely or within close proximity to protected areas, we added a 1 km buffer on all installations. Using the intersection tool in QGIS, we identified installations intersecting with protected areas as those violating the best practice that requires installations to be at least 1 km away from protected areas. We used a similar approach to find installations violating the 200 m buffer from the shoreline of water bodies. We added a 200 m inner buffer on the lakes and using the intersection tool, we selected installations within the buffer zone thus violating the best practice. For each water body, the number of cage aquaculture installations violating

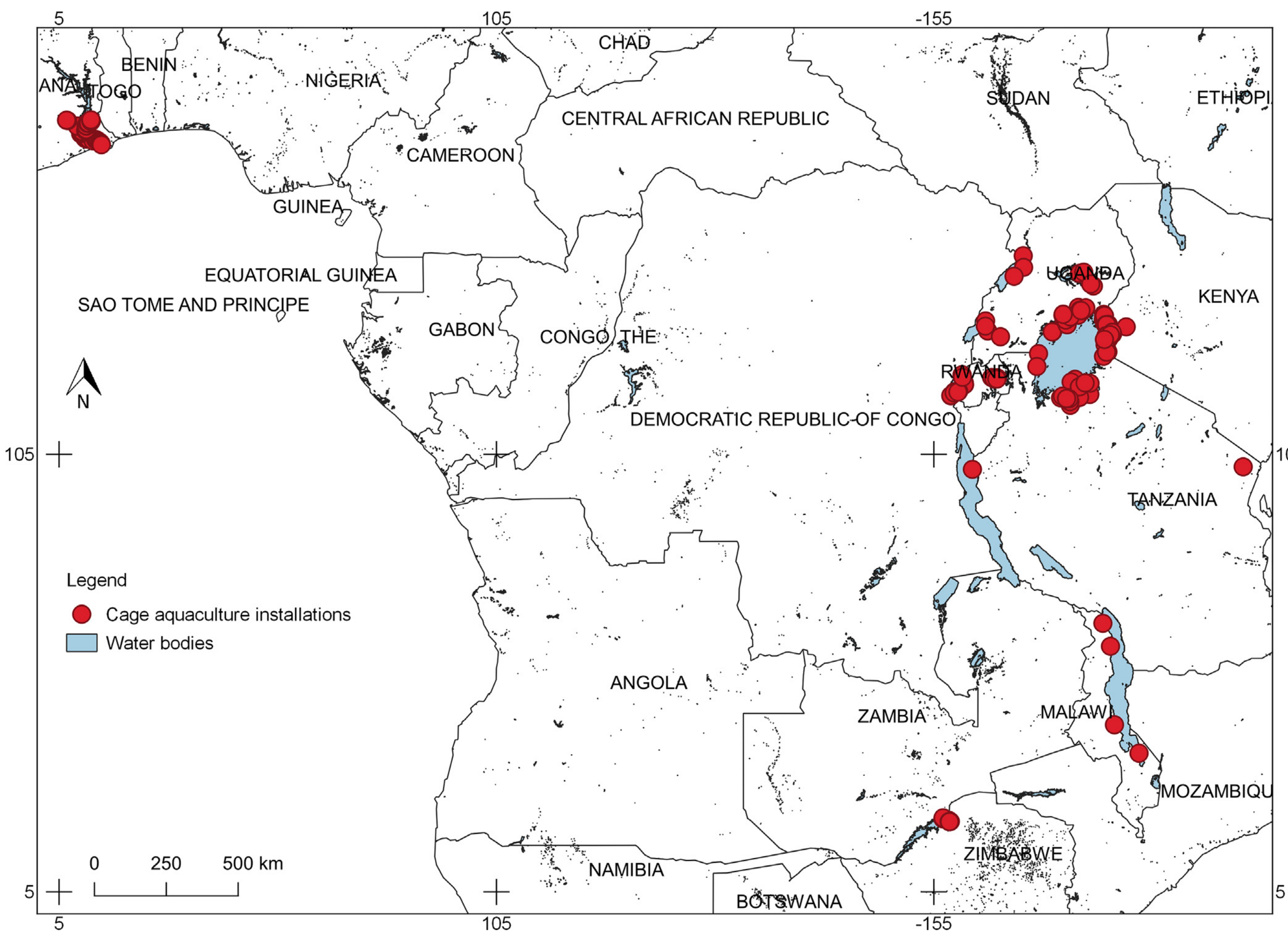

Fig. 1. The distribution of cage aquaculture installations on African inland waters.

Please cite this article as: L. Musinguzi, J. Lugya, P. Rwezawula et al., The extent of cage aquaculture, adherence to best practices and reflections for sustainable aquaculture on African inland waters, Journal of Great Lakes Research, https://doi.org/10.1016/j.jglr.2019.09.011

each of the best practices was expressed as proportion of total installations.

Results

Magnitude of cage aquaculture installations on African inland waters

On the African inland waters, we found 263 cage aquaculture installations on 18 water bodies, within eight countries (Fig. 1). The water bodies include five of the African Great Lakes i.e. Victoria, Malawi, Albert, Tanganyika and Kivu as well as other important water bodies such as the River Nile and River Volta (Table 1). Among countries, Ghana is home to most of the cage aquaculture installations with 36.1% of the installations, followed by Uganda (17.9%), Kenya (16.4%), Tanzania (13.3%), Rwanda (8.0%), Zimbabwe (3.8%), Zambia (3.0%) and Malawi (1.5%). With 39.9% of all the installations, Lake Victoria had the highest number of cage aquaculture installations of all the water bodies (Table 1). Lakes Victoria, Kariba, Volta and River Volta comprise 82.9% of all cage aquaculture installations and could be designated as the major cage aquaculture areas in Africa (Fig. 2).

The majority of aquaculture installations (77.7%) were confirmed within the GEE. The number of cages at each of the aquaculture installations reflects a diverse magnitude for cage aquaculture on African inland waters from small to large fish farms (Table 1). Lake Victoria tops the water bodies with an estimated 12,086 cages and an average of 115 ± 394 cages at each installation. Lakes Victoria and Volta had the largest area under cages with 176.9 ha and 33.6 ha respectively (Table 2). The area under cages in the lakes is still negligible compared to the total surface area of the lakes.

Adherence to best practices

We found partial adherence to best practices, pertaining the establishment of cage aquaculture installations on the water bodies. Data on the distance of siting of installations from the shoreline indicated occurrence of cage aquaculture installations exclusively in waters near the shores (ESM Fig. S1). Cages are sited furthest from the shoreline on Lake Malawi and nearest to the shore in Lake Volta and River Volta (Table 2). On Lake Volta and River Volta, some installations have no separation between water and the shoreline. Spatial analyses indicated that 138 installations were located within the 200 m distance from the shoreline of lakes, contrary to best practices. This includes 61 installations on rivers such as Volta (Ghana), the Nile (Uganda) and small water bodies which do not offer the possibility of the buffer because of their shape or size. On Lake Victoria, the majority of such installations (43.2%) are in Tanzania and least in Uganda (25%).

We found 27 cage aquaculture installations located entirely within protected areas or <1 km away from the protected areas (ESM Fig. S2). These installations, found in only Uganda and Zimbabwe intersected with protected areas designated as forest reserves, community wildlife management areas, Ramsar site (wetland of International Importance under the Ramser conven-

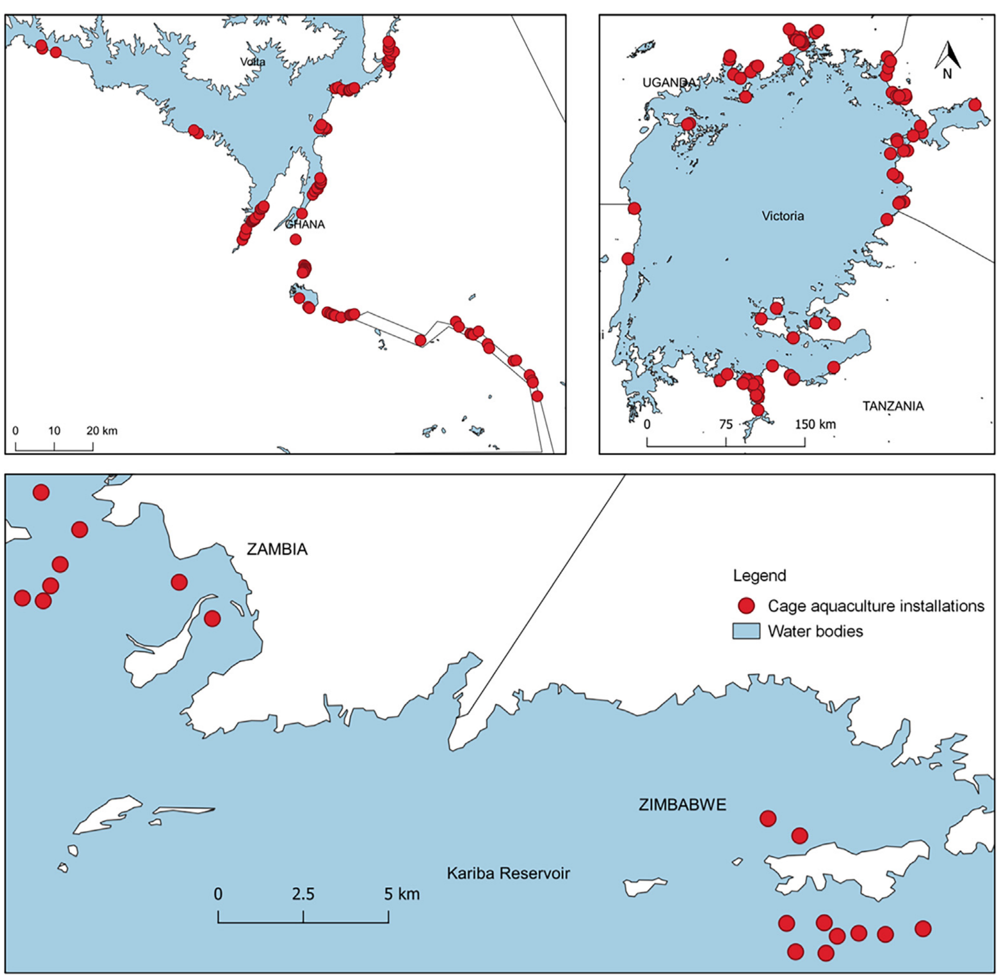

Fig. 2. Major cage aquaculture areas on the African inland water bodies. These areas hold majority of cage aquaculture installations (82.9%).

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Table 1
Cage aquaculture installations and estimated number of cages on African inland water bodies. The range and average (mean ± SD) for the number of cages are provided. Number of cages are available only for water bodies that had installations confirmed within Google Earth Engine (GEE).

Water body	Number of cage aquaculture installations	Percentage of the total number of cages	Country(ies) of installations (number & percentage given for more than one country)	Estimated total number of cages	Range	Mean ± SD
Lake Victoria	105	39.9	Kenya (43(40.95%)), Tanzania (33(31.43%)), Uganda (29 (27.62%))	12,086	1–3141	115.1 ± 394.8
Lake Volta	55	20.9	Ghana	3817	2–700	69.4 ± 122.8
River Volta	40	15.2	Ghana	3184	2–540	79.6 ± 138.8
Lake Kariba	18	6.8	Zambia (8(44%)), Zimbabwe (10 (56%))	254	3–29	14.1 ± 7.1
Lake Kivu	12	4. 6	Rwanda	208	1–38	17.3 ± 11.2
Lake Muhazi	9	3.4	Rwanda	199	4–50	22.1 ± 13.7
River Nile	8	3.0	Uganda	135	4–60	16.9 ± 17.8
Lake Malawi	4	1.5	Malawi	53	4–32	13.3 ± 16.2
Lake Albert	2	0.8	Uganda			
Lake Kyoga	2	0.76	Uganda	102	39–63	51 ± 17.0
Kazinga channel (river)	1	0.4	Uganda	10	10	10 ± 0
Lake George	1	0.4	Uganda	10	10	10 ± 0
Lake Kawi	1	0.4	Uganda	3	3	3 ± 0
Lake Kumba	1	0.4	Tanzania	40	40	40 ± 0
Lake Mugogo	1	0.4	Uganda			
Lake Pallisa	1	0.4	Uganda	4	4	4 ± 0
Lake Tanganyika	1	0.38	Tanzania			
Reservoir	1	0.38	Uganda	10	10	10 ± 0
Total	263	100		20,114		

Table 2
Estimated area of coverage (hectares), percentage of total lake area, and distance (range and mean ± SD) between the shoreline and cages. Estimates were available only for water bodies with cage aquaculture installations confirmed within the Google Earth Engine (GEE).

Water body	Estimated total area covered by cages (hectares)	Percentage (%) of total lake area	Distance of cages from the shoreline (m)	
			Range	Mean ± SD
Lake Kariba	33.6	6.2E-03	220.2–1759.8	894.4 ± 418.5
Lake Kivu	4.3	1.6E-03	5–120.1	41.3 ± 39.2
Lake Kumba	0.2	2.5E-01	N/A	66.7
Lake Malawi	1.0	3.4E-05	NA	1100
Lake Muhazi	4.7	1.4E-01	48.23–150	82.6 ± 37.5
Lake Tanganyika	0.01	1.7E-07	141.99–142.0	141.99
Lake Victoria	176.9	2.6E-03	21–665	211.6 ± 157.3
Lake Volta	105.4	1.2E-02	0–860	191.7 ± 157.6
River Nile	1.16	-	13.4–621	178.5 ± 269.9
River Volta	21.9	-	0–321	30.2 ± 52.4

tion), national park, biosphere reserve, wildlife reserve, and wildlife sanctuary in Uganda, and a recreational park in Zimbabwe. Considering the data on depth available from Lake Victoria, installations were sited in waters of a depth range of 2.1–56.3 m but with 82% of the installations within waters of $\geq$5 m depth. Considering data on Chl a, only Lake Malawi had installations in either oligotrophic or mesotrophic (non-eutrophic) waters with Chl a concentration ranging from 0.62 to 7.32 mg/L (mean = 3.1 ± 3.1 mg/L). On Lake Kariba, the Chl a ranged from 13.6 to 33.64 (mean = 21.9 ± 5.2 mg/L) and 33.3% of the installations were in mesotrophic waters and the rest in eutrophic waters. On Lake Victoria, the majority of installations (73.9%) were in eutrophic waters, reflecting the average Chl a concentration of 39.1 ± 18.4 mg/L (range = 6.9–90.3 mg/L). An equal proportion of installations of 13.0% were in either mesotrophic or hypertrophic (>56 mg/L) waters. On Lake Albert, all installations were in eutrophic waters (24.8 ± 0.9 mg/L; range 24.17–25.49 mg/L).

Discussion

Our results demonstrate that cage aquaculture on the African inland waters has expanded to a considerable magnitude. By 2006, cage aquaculture was confirmed at pilot stage on lakes Volta (Ghana), Victoria (Uganda and Kenya), Malawi (Malawi), Kariba (Zambia) and was commercial only in Zimbabwe on Lake Kariba (Blow and Leonard, 2007). At that time (2006), these water bodies together hosted only nine cage aquaculture installations compared to 263 installations identified on African inland waters at the present time (Table 1). At that time, the installations on all the water bodies shared only 185 cages with 17 cages on Lake Volta (Ghana), 10 cages on Lake Malawi, 30 small cages (4 m^3) on Lake Victoria (Kenya), 15 cages on Lake Victoria (Uganda), 84 cages on Lake Kariba (Zimbabwe) and 30 cages on the same lake in Zambia. With 20,114 cages estimated to be extant on the African inland waters now (Table 1), cage aquaculture has expanded. It has expanded to cover more water bodies particularly in Uganda and more countries (Rwanda, Zambia and Tanzania) today (Tables 1; Figs. 1, 2). Cage aquaculture on the African inland lakes is no longer under pilot but is fully established and commercial.

Noteworthy, the number of installations and cages could be higher than reported since we were unable to identify some cage aquaculture installations in some lakes. Some water bodies where cage aquaculture reportedly occurs but no installations were identified include Lake Tanganyika in Zambia and some lakes in Nigeria

(Adegboye, 2010; http://thenationonlineng.net/boosting-cage-fish-farming/, accessed on 19th feb 2019). Like Blow and Leonard (2007), we were unable to confirm cage aquaculture in countries such as Ivory Coast. With benefits from cage aquaculture and national aquaculture development strategies inspiring more developments (Clotilde and Judith, 2014; Rothuis et al., 2014; https://www.the-star.co.ke/news/2018/01/31/kisumu-builds-sh12bn-fish-cage-and-processing-plant-to-boost_c1705445), cage aquaculture on African inland waters will continue to expand.

The differences in number of cage aquaculture installations and number of cages among water bodies or countries (Table 2), demonstrate diversity in investments and interest in cage aquaculture on the African inland waters. Assuming that each installation denotes an individual farm or investment (this is not always the case as one farm can have cages on multiple sites), the mean and range of cages indicate that cage aquaculture has been embraced by both small scale and large-scale fish farmers. Cage aquaculture is more diversified on lakes Victoria and Volta as well as River Volta, corresponding to the highest number of cage aquaculture installations. On some of the water bodies, there are individual installations with exceptionally high number of cages (Fig. 3), a sign of large-scale investments in cage aquaculture, likely unmatched by pond-based fish farming in the region.

The expansion of cage aquaculture on the African inland water bodies reflects the increasing global interest in cage aquaculture in both fresh and marine waters (Halwart et al., 2007; Chen et al., 2008). Global growth of cage aquaculture is attributed to the increasing demand for fish (Merino et al., 2012; FAO, 2018), potential offered by available water resources (Gentry et al., 2017) and its high production potential. For instance, in Europe, at only 28% of total production space by volume, cage aquaculture generated 50% of total aquaculture direct output value in 2012 and its expansion could increase total aquaculture production by 55% by 2030 (Bostock et al., 2016). Besides, cage aquaculture offers advantages over other aquaculture systems, particularly pond-based fish farming such as easier routine farm management practices, higher fish production per unit volume, and cheaper establishment costs (Beveridge, 1984). These advantages address common challenges faced by aquaculture in Africa (Brummett et al., 2008), and could be the greatest incentive for cage aquaculture development on African inland water bodies. In addition, the large surface area of the African inland water bodies and availability of suitable native culture species offer high potential.

A set back to cage aquaculture development is its potential challenges to freshwater ecosystems, biodiversity and dependent ecosystem services. Besides the advantages, Beveridge (1984) listed limitations of cage aquaculture, accentuating the environmental challenges incurred on holding water bodies. Currently, cage aquaculture is consensually believed to cause eutrophication, habitat degradation, spread of diseases, and deterioration of genetic diversity of wild populations (Beveridge, 1984, Rust et al., 2014; Price and Morris, 2013; Aguilar-Manjarrez et al., 2017; Wringe et al., 2018). In addition, cage aquaculture can lead to conflicts with other uses such as fishing, recreation, transport and conservation. On the African inland waters, these challenges are likely as the cage aquaculture is intensive, sustained by feeding cultured fish exclusively on externally formulated feeds which can worsen environmental challenges from cage aquaculture (Beveridge, 1984).

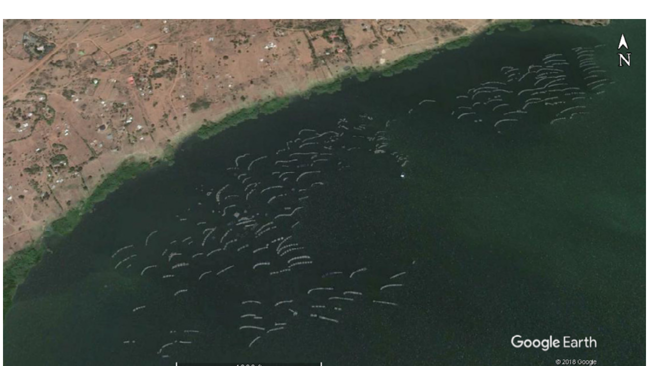

Fig. 3. Example of a cage aquaculture installation with a large number of cages (about 3140) on Lake Victoria, Kenya (Location coordinates (decimal degrees): Lat: −0.09581; Long: 34.07928).

The possibility of these challenges is made more certain by the ongoing establishment of cage aquaculture enterprises without total adherence to best management practices as demonstrated by our results. Locating cages in nearshore areas, close to protected areas, shallow waters, and in areas of excessive nutrients is contrary to best practices for sustainable cage aquaculture. Locating cages in nearshore and shallow areas increases overlap of cage aquaculture with fragile habitats for aquatic species including fish. More so, in most lakes such as Lake Victoria, these areas are already eutrophic or hypertrophic (Hecky, 1993; Hecky et al., 2010), and therefore cage aquaculture could exacerbate environmental challenges. Depending on the scale, these impacts could devastate the biodiversity attributes of African inland lakes and dependent fisheries resources useful for food security, employment, and revenue generation (FAO, 2014; De Graaf and Garibaldi, 2014). Regarding best management practices, our approach could not ascertain whether some cage aquaculture installations found in sites with excessive nutrients may have contributed to this by degrading the water quality of previously suitable sites.

Ignoring best practices during establishment of cage aquaculture is not only detrimental to the environment but could also disrupt cage aquaculture investments. This possibility should be recognized as an incentive for promoting best practices among fish farmers and prospective farmers. In several instances, farmers have been forced to remove cage aquaculture installations from lakes and rivers for environment reasons such as fish kills. In China, farmers were forced to remove cages from lakes and rivers in response to a new directive for proper zoning (FAO, 2018). Similar decisions have been experienced in Phillipines on Taal lake and River Pansipit (https://thefishsite.com/articles/illegal-fish-cages-in-taal-lake-to-be-dismantled, Accessed 25th February 2019), and in Indonesia on Jatiluhur Reservoir (https://ussec.org/indonesia-removes-thousands-fish-floating-cages-jatiluhur-reservoir/., Accessed 25th February 2019).

Despite the expansion, there are no reports of adverse or catastrophic impacts of cage aquaculture on African inland water bodies. However, it has been associated with loss of nutrients to water on Lake Malawi (Gondwe et al., 2011a), low dissolved oxygen, increased ammonia concentration around cages and eutrophication of Lake Victoria (Njiru et al., 2018). In the Lake Volta system, non-native strains of tilapia originating from Asia have escaped from cage fish farms and are interbreeding with native strains (Anane-Taabeah et al., 2019). A substantial concern developed when Tilapia Lake Virus, a dangerous virus that can terminate populations (Jansen et al., 2018), was reportedly identified in both wild and farmed Nile tilapia on Lake Victoria (Mugimba et al., 2018). Although the detection was later refuted (*Pesacheck*, December 13, 2018; https://pesacheck.org/false-there-is-no-outbreak-of-deadly-tilapia-lake-virus-in-lake-victoria-63d5d0e59555), this would have gone on record as the first major impact of cage aquaculture. The level of impacts on the African waters is still minimal probably because area under cage aquaculture is still negligible compared to the size of the water bodies. For instance, our results indicated 176.9 ha as the area under cages on Lake Victoria, which is a mere 0.0026% of the lake's total surface area (Table 2). In addition, some cage aquaculture installations have been strategically placed to ensure that wastes from the cages are dispersed to avoid local level adverse impacts (Gondwe et al., 2011b).

Implications for cage aquaculture development on African inland waters

The challenges of cage aquaculture can be abated by adhering to best management practices during planning, siting and operation (Bueno et al., 2013; Price et al., 2015; Aguilar-Manjarrez et al., 2017). If cage aquaculture development is managed properly, it could be sustainable, benefiting farmers with minimal undesirable impact on the environment and other water uses. Ideally, setting up a framework for sustainable cage aquaculture requires several considerations, but the following list of key aspects should be considered as priority for the development of sustainable cage aquaculture of the African inland waters.

Establishment of zones with full adherence to best practices

Proper establishment of cage aquaculture installations exclusively in suitable and capable water bodies or specific sites within water bodies can avoid detrimental impacts on the environment and conflicts with other uses. Zoning could allow the exclusion of areas that overlap with features such as protected areas (Bueno et al., 2013), and exclude shallow lakes (average depth 5 m or less) such as lakes Kyoga and George in Uganda that were found with cages. Just as there are plans to transfer marine coastal aquaculture to offshore areas (Lester et al., 2018), zoning on African waters should consider prohibiting cage aquaculture near the shoreline and exclude water bodies such as rivers, small lakes and reservoirs. The hindrance to restricting cage aquaculture offshore is that growing fish offshore increases operational costs but could help farmers avoid near shore waters that are either eutrophic or vulnerable and safeguard other water uses.

Development and promoting best practices

Concerted efforts are required to develop best management practices. In addition to best practices associated with zoning sustainable and capable sites (e.g. Bueno et al., 2013), there are applicable best practices that should be adhered to during the operational stages of cage aquaculture. These practices include encouraging the farming of native fish species, use of appropriate stocking rates, maximizing feeding efficiency, minimizing contamination, disease surveillance, maintaining production information, environmental monitoring and farm decommissioning. The development of the best practices should engage and train farmers not only to promote best practices but also to equip them with skills and knowledge for implementation. Engaging farmers is critical as good farm management can avoid adverse impacts of cage aquaculture (Price et al., 2015). An example on African inland waters is on Lake Malawi where good farming practices were associated with a lower amount of nutrients lost to surrounding water (Gondwe et al., 2011b).

Development of regulatory frameworks and institutions where they are not available

The adherence to designated zones and best practices adeptly requires strong regulatory frameworks and institutions to be effective (Lester et al., 2018). These should be developed where they do not exist and enforced where they exist. In addition to public institutions, producer (farmer) organizations should be strengthened . These have proven to be beneficial in guiding aquaculture practices to minimise negative impacts on the environment (Hishamunda et al., 2014).

Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

This work was funded by the African Great Lakes Conservation Fund administered by The Nature Conservancy with funding from John D. and Catherine T. MacArthur Foundation to whom we are grateful. The funders were not involved in the design of the study or preparation of the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jglr.2019.09.011.

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Please cite this article as: L. Musinguzi, J. Lugya, P. Rwezawula et al., The extent of cage aquaculture, adherence to best practices and reflections for sustainable aquaculture on African inland waters, Journal of Great Lakes Research, https://doi.org/10.1016/j.jglr.2019.09.011