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REVIEW

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Aquaculture in Africa: A Comparative Review of Egypt, Nigeria, and Uganda Vis-À-Vis South Africa

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ABSTRACT
This study reviews the development and conventional qualitative analysis of aquaculture in Africa, specifically by reviewing the aquaculture sector of key players (Egypt, Nigeria and Uganda) as a reference for South Africa; an aspiring key aquaculture player in Africa based on the launch of Operation Phakisa—South African version of the blue economy initiative. The key players were identified based on current annual production output and critical success factors, thus used as a benchmark for South Africa. Qualitative factors reviewed are critical success factors of the aquaculture sector of the selected countries that are widely germane to aquaculture development. These factors include production outputs (tons) and value ($); cultured species; prevalent aquaculture production systems; types of aquaculture, i.e., freshwater and mariculture; aquaculture development challenges related to fish seed, fish feed, land and water availability; aquaculture market and trade and provision of enabling environment through policies and frameworks. These factors were qualitatively reviewed and analyzed in ranking the aquaculture operations of the key players and South Africa to elucidate the critical success factors and challenges.

KEYWORDS
Aquaculture; Egypt; Nigeria; Uganda; South Africa

Introduction

Aquaculture was first introduced to many countries in Africa at the turn of the 20th century mainly to satisfy colonial recreational fishing needs (Hecht et al. 2006). In the 1920s, tilapia were successfully produced in static water ponds in Kenya (FAO 2005-2020e). Aquaculture as a means of sustainable food production was later introduced by the colonial governments across Africa between the 1940s and 1950s (Brummett et al. 2008) with the objectives of improving nutrition in rural areas, supplementary income generation, diversification to reduce crop failure risks and employment creation in rural areas. As a result, many fish farming stations were built by the government in the 1950s (Fisheries 2006), with about 300,000 active production ponds in the whole of Africa as at the end of 1950 (Satia 1989).

The FAO, in partnership with governments, donor countries, national and international research bodies and non-governmental organizations began to spearhead the development of aquaculture in the region since the 1960s (Hecht et al. 2006). Efforts were focused on elementary research and development to understand practical techniques for a range of mostly indigenous species. The development of aquaculture in the region was expedited through increased financial and technical aids from bilateral and multilateral donors worth about US$ 500 million from the early 1970s to early 1990s (Hecht et al. 2006). Subsequently, financial support for aquaculture in Africa significantly regressed due to donor priorities shifting toward other pressing challenges such as education, health, HIV/AIDS and good governance in Africa (Hecht et al. 2006). The development of aquaculture in Africa can be broadly segmented into three phases (Table 1).

Current status of aquaculture in Africa

The African contribution to world aquaculture production is still insignificant (∼2.7%) (Halwart 2020) albeit significantly increasing with larger-scale

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Table 1. Evolution of aquaculture in Africa.

Phase	Period	Description of activities
I	1950–1970	• Introduction of aquaculture • Limited knowledge and understanding of aquaculture • Fish farms were built by governments
II	1970–1995	• Expansion of aquaculture • Significant donor support • Active R&D • Government involvement in seed supply and extension services • Commercialization of aquaculture in some countries such as Nigeria, Madagascar, Côte d'Ivoire, Zambia and South Africa
III	1995–till today	• Reduced donor support • Emergence of Commercial aquaculture • Re-orientation of public Support toward facilitation

Adapted from Hecht et al. (2006).

investments in Egypt, Nigeria, Uganda and Ghana producing substantial quantities of fish (Cai et al. 2017; FAO 2018). The region recorded a twenty-fold production increase from 110,200 to 2,196,000 tons from 1995 to 2018 with a compound annual growth rate (CAGR) of 15.55% (FAO 2016; Halwart 2020). The growth of aquaculture production was due to the advent and intensification of private sector controlled small and medium scale enterprises (SMEs; Satia 2011). Also, the development of big commercial enterprises mostly stimulated by the combination of burgeoning public support, expertise, foreign direct investment, interest in aquaculture, global awareness raised through the New Partnership for Africa's Development (NEPAD) Fish for All Summit of 2005 as well as the implementation of the FAO Special Program for Aquaculture Development in Africa (SPADA) contributed to aquaculture growth (Satia 2011).

Most of the production (99%) are from the inland freshwater systems and is mostly dominated by the culture of indigenous and abundant species of tilapia and African catfish while mariculture only contributes a meager 1% to the total production quantity, although it is an emerging and promising subsector (FAO 2016, 2018). New aquaculture production systems such as tanks and cages were introduced as well as the improvement of current production systems (Satia 2017). The aquaculture sector employs about 6.2 million people in Africa, with a large share of the employees being women that are engaged in largescale commercial farms (Satia 2016). Women are primarily involved in the downstream postharvest and marketing operations of the aquaculture value chain (Satia 2016). The aquaculture sector, therefore, has the potential to significantly contribute to food security, reduce unemployment rates and economic development of Africa.

Many governments in Africa have started realizing the importance of creating an enabling business environment by taking steps such as expediting, coordinating and adopting policy reforms to create a conducive environment for business to thrive, with ripple effects on the aquaculture sector (Satia 2011). Some countries have developed and adopted aquaculture-centered policies and strategic framework as a roadmap to guide development (Machena and Moehl 2001). Few governments facilitated the provision of soft credits and incentives, however, access to affordable credit, sufficient quality and quantity of inputs and land ownership still constitute major constraints to the development and intensification of the aquaculture sector (Satia 2011).

Generally, research activities in the region focused on the species characterization, selective breeding and low-cost diet production in some centers (Satia 2011). On-farm participatory research approach using model farms and private enterprises are yielding fast aquaculture technologies transfer via farmer-to-farmer pathways in the target countries administered by SPADA (Cocker 2014). Extension services are generally inadequate and weak; therefore, the pressing need to develop and strengthen the links between research and development (Satia 2011).

Some countries have witnessed growing private sector-led participation in the production and delivery of major aquaculture inputs such as seed and feeds while other countries host the manufacturers and suppliers of aquaculture equipment (Koge et al. 2018). Association of aquaculture products producers is located in many countries of Africa playing key roles such as information transfer, knowledge exchange and facilitation of aquaculture related activities (Satia 2017). The formation of clusters of fish farmers has efficiently contributed to support services delivery, economies of scale, reduction of transaction costs and competitiveness (Satia 2017).

The intra- and inter-distribution of aquaculture products within the region are hampered by dilapidated infrastructure and the dearth of facilities, however, the advent of fledging aquaculture marketing activities in some countries is contributing to aquaculture value chain improvement (Satia 2011). In order to

Table 2. Top 10 aquaculture producers in Africa in 2018 (FAO 2003-2020a, 2003-2020c, 2004-2020, 2005-2020d, 2005-2020f, 2005-2020c, 2005-2020a, 2005-2020, 2007-2020, 2010-2020b).

No.	Country	Production (metric tons)	Regional share (%)	Global share (%)
1	Egypt	1,561,457	71.10	1.90
2	Nigeria	291,233	13.26	0.35
3	Uganda	103,737	4.72	0.13
4	Ghana	76,630	3.49	0.09
5	Zambia	24,300	1.11	0.03
6	Tunisia	21,756	0.99	0.03
7	Kenya	15,124	0.69	0.02
8	Malawi	9014	0.41	0.01
9	Madagascar	7421	0.34	0.01
10	South Africa	6181	0.28	0.01

meet the demand for ready-to-prepare products by consumers, artisanal fish processing sub-sectors are emerging from farm gates and markets utilizing simple fish processing methods (Satia 2017). Value addition is also carried out on the products by freezing, smoking, drying, as well as cold smoking of catfish fillets for export to European markets (Satia 2017).

The top aquaculture producers in Africa are Egypt, Nigeria, Uganda, Ghana, Tunisia, Kenya, Zambia, Madagascar, Malawi and South Africa (Satia 2011; Satia 2017). These key aquaculture producers experienced remarkable growth in the past decade as a result of several factors such as capacity building in critical subject areas, embracing good governance, research and development, access to credit facilities and mainly due to the promotion of private sector-led aquaculture development (Satia 2017). Private sector-led initiatives gave rise to investments in sound management, emerging production systems, the formulation and utilization of aqua-feeds and the emergence of dynamic and robust producer associations and service providers (Satia 2011).

As the industry evolves and activities get intensified, aquaculture in some of the leading countries become confronted with challenges such as; the burgeoning demand for capital; inadequate quantities and quality of seed and feeds; resource (land/water/feed) competition; requirement to reinforce aquaculture management and overall governance of the sector (Satia 2016). The peak in both marine and inland capture fisheries yield, combined with growing markets and services, urbanization, private-sector development opportunities; make the prospects of aquaculture development are huge (Satia 2017).

Comparative analysis of key regional players (Egypt, Nigeria and Uganda) vis-à-vis South Africa

The contribution of Africa to global aquaculture production in 2018 was estimated at 2196 million tons representing an insignificant 2.67% and dominated mainly by the production of freshwater finfish (Halwart 2020). The leading producers - Egypt, Nigeria and Uganda, account for about 90% of total aquaculture production from the region (Table 2). The aquaculture industry in Egypt experienced rapid development from 1998 due to the consistent and cumulative interventions by the Egyptian government over the past years, as well as growing private sector-driven investment (Soliman and Yacout 2016). Aquaculture production in Egypt, therefore, grew from 139,389 tons in 1998 to 1,561,457 tons in 2018 (Figure 1), representing 71% of total aquaculture production in Africa (FAO 2003-2020b). Nigeria with a population of over 200 million (Pison 2019), has the highest fish demand in Africa, resulting in the rapid development of peri-urban commercial aquaculture (Cai et al. 2017). As a result of the market-driven development, aquaculture production grew from 20,458 tons in 1998 to 291,233 tons in 2018 (Figure 2). The Nigerian government is saddled with the responsibility of providing a conducive business environment, while the entire aquaculture value chain development is driven by the private sector initiatives (FDF 2012). The development of aquaculture in Uganda gained momentum from 2000 due to the growing awareness of the potential of aquaculture to address malnutrition, food insecurity and unemployment (Cai et al. 2017). As a result, aquaculture development received a boost through strategic interventions from the government and aids from developmental partners (Cai et al. 2017). Aquaculture production increased from 2360 tons in 2001 to 103,737 tons in 2018 (Figure 3). As a result of the significant leap in aquaculture production output of Egypt, Nigeria and Uganda in the past two decades, it is noteworthy to review the critical success factors of these key regional players. Out of the top ten aquaculture producers in Africa, Egypt, Nigeria, Uganda, and Ghana contribute about 93% of total regional production output (Table 2).

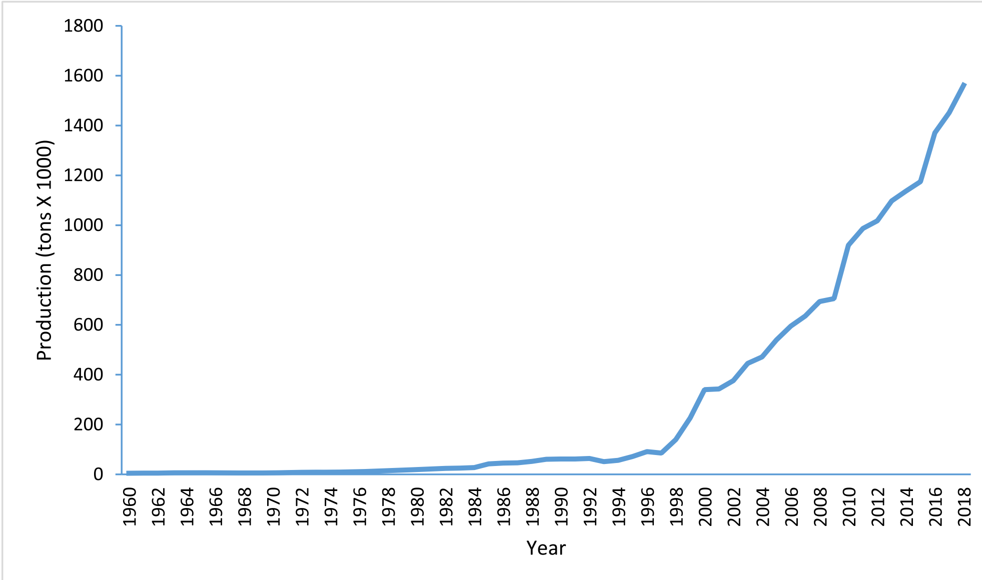

Figure 1. Aquaculture production in Egypt (1960–2018 in tons ×1000) (FAO 2003-2020c).

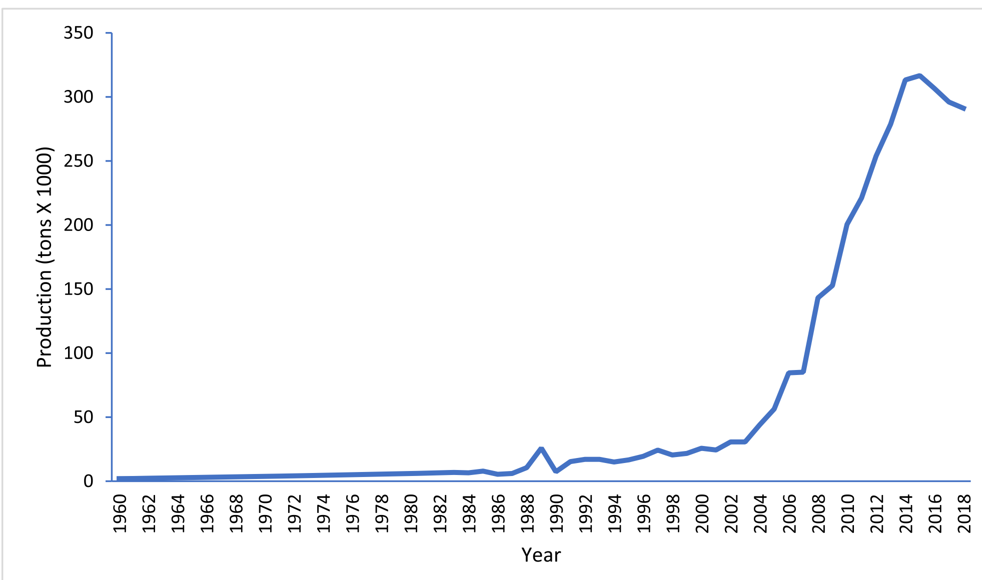

Figure 2. Aquaculture production in Nigeria (1960–2018 in tons ×1000) (FAO 2007-2020).

Aquaculture in Egypt

The practice of aquaculture in Egypt dates back several millennia, albeit modern management practices were only recently adopted to maximize production output (Shaalan et al. 2018). In the past two decades, the Egyptian aquaculture industry has been experiencing rapid development due to paradigm shift from traditional extensive to semi-intensive aquaculture systems and modern intensive aquaculture systems (FAO 2003-2020b). Also, factors such as the emergence of new technologies for the formulation and production of aquafeed (i.e. extruded feed), adoption of best farm management practices and prioritization of the aquaculture industry development by the government contributed immensely to the fast expansion of the sector (FAO 2003-2020b; USDA 2016).

Aquaculture production and value

The annual production of Egypt exceeds one and a half million tons with a market value estimated at over USD 2 billion, ranking the country 6th amongst the leading aquaculture producing countries globally in 2018 (FAO 2003-2020b; Shaalan et al. 2018). The aquaculture industry in Egypt contributes 77% of the total national fisheries production and employs more

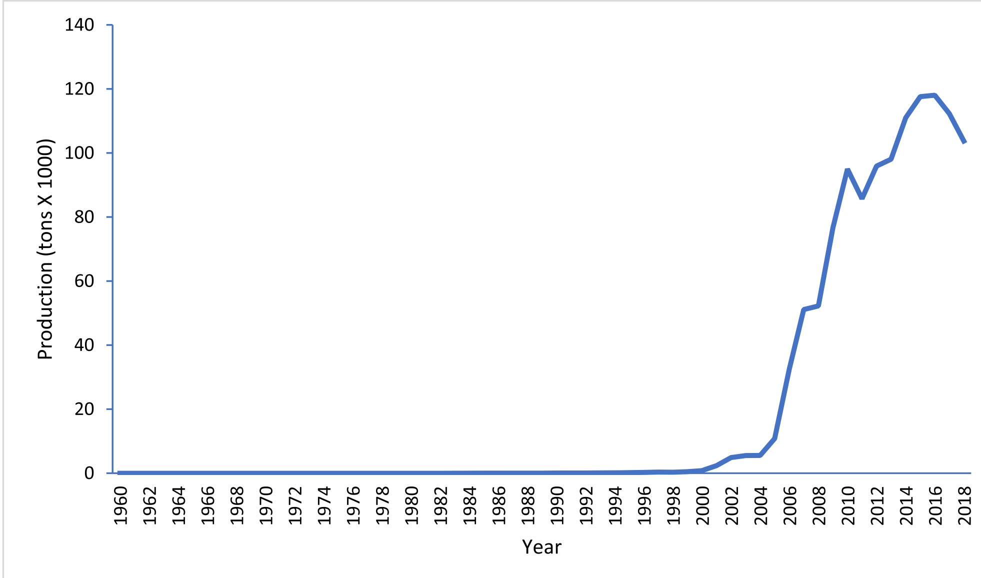

Figure 3. Aquaculture production in Uganda (1960–2018 in tons ×1000) (FAO 2004-2020).

Table 3. Aquaculture production quantity in Egypt by species in 2014 (Shaalan et al. 2018).

Fish species	Production quantity (tons/year)
Nile tilapia	759,601
Carps	198,829
Mullet	119,645
Gilthead Seabream	16,967
European Seabass	15,167
Catfish	14,109
Penaeus shrimp	7235
Meager	5884
Total	1,137,437

than 580,000 workers (El-Sayed et al. 2015; FAO 2016; Shaalan et al. 2018). Assessment of fisheries stocks in the fishing areas of both Mediterranean and Red sea shows minimal potential for an increase in capture fisheries production (Soliman 2017). Thus, the need for aquaculture production expansion to bridge the growing demand-supply gap for fisheries products (Nassr-Alla 2008).

Cultured species in Egypt

The aquaculture industry in Egypt is characterized by the culture of diverse species of finfish and shellfish (Table 3). Tilapia species are the most cultured aquaculture species in terms of production quantity and account for about 67% of total cultured species in 2014 (Soliman and Yacout 2016; Shaalan et al. 2018). The other commonly cultured fish species are mullet, Gilthead seabream, European seabass, Penaeus shrimp, Catfish and Meager (Soliman and Yacout 2016; Shaalan et al. 2018).

Commonly cultured tilapia species are—Nile tilapia (*Oreochromis niloticus*), blue tilapia (*O. aureus*) and the hybrid red tilapia (Sadek 2011; Shaalan et al. 2018). Before the 1990s, tilapia species were harvested as incidental catch from carp fishponds; however, production of cultured tilapia in Egypt currently ranks second globally after China (FAO 2003-2020a; Norman-López and Bjørndal 2009). The industry is characterized by the production of sex-reversed all-male tilapia fry for economic reasons, as they grow faster to attain market weights with better Feed Conversion Ratios (FCR) (Beardmore et al. 2001; Shaalan et al. 2018). Despite the enormous size of the Egyptian tilapia industry, they are highly restricted from exporting to the EU and USA due to inability to meet the stringent food safety standards of these markets; therefore, all the tilapia produced are currently consumed locally (Norman-López and Bjørndal 2009; Soliman and Yacout 2016; Shaalan et al. 2018).

Carp production contributes about 17% to total aquaculture production in Egypt and ranks second after tilapia. Commonly cultured species of carp are common carp (*Cyprinus carpio* – L. 1758), silver carp (*Hypophthalmichthys molitrix* – Valenciennes, 1844), and grass carp (*Ctenopharyngodon Idel*la – Steindachner, 1866) (Hagar Dighiesh 2014; Shaalan et al. 2018).

Production of mullet species account for about 10.5% of total aquaculture production in Egypt and rank third after carp (GAFRD 2014). Cultured species of mullet include flat-head gray mullet (*Mugil cephalus* – L. 1758), thin-lipped mullet (*Liza ramada* – Risso 1827), thick-lip gray mullet (*Chelon labrosus* –

Risso 1827), black keeled mullet (*Liza carinata* – Valenciennes, 1836) golden gray mullet (*Liza aurata* – Risso 1827), leaping mullet (*Liza saliens* – Risso 1810) and bluespot mullet (*Valamugil seheli* – Forsskål, 1775) (Hagar Dighiesh 2014; Sadek 2016; Shaalan et al. 2018). Egypt is the highest global producer of cultured flat-head gray mullet (Sadek 2016), as they are the mullet species of choice for farmers because of their fast growth rate and large size (Saleh 2008). Culture of mullets is mostly dependent on fry caught from the wild and subsequently stocked in lakes as monoculture species or polyculture with tilapia and carp (Sadek and Mires 2000; Saleh 2008; Shaalan et al. 2018). The thin-lipped mullet accounts for the largest share of mullet production from farms due to greater fry availability as compared to the flat-head gray mullet (Sadek and Mires 2000).

Marine fish species commonly cultured in Egypt are European sea bass (*Dicentrarchus labrax* – L. 1758) and gilthead seabream (*Sparus aurata* – L. 1758) which both account for about 3% of total aquaculture production (GAFRD 2014). The combined production of both species contributes about 2.8% of the total fish farm production (GAFRD 2014). Production of Meager (*Argyrosomus regius* – Asso 1801) started in 2008 with nearly 2000 tons and grew to almost 6000 tons in 2014 (Rothuis et al. 2013; Shaalan et al. 2018).

Production of African catfish (*Clarias gariepinus*) accounts for only 1% of the total fish production in Egypt (GAFRD 2014) as they are commonly polycultured with tilapia to increase fish yield from the same farm and to control the prolific reproduction of tilapia (Ibrahim and Naggar 2010). Koi carp and molly are cultured; however, on a very small scale for the ornamental fish trade (Sadek 2011).

Egypt produces cultured shellfish (*penaeid* shrimp and giant freshwater prawn) in semi-intensive systems with annual production above 7000 tons and imports about 55,000 tons per year to bridge the local demand-supply gap for shrimps (Sadek 2011; Rothuis et al. 2013; GAFRD 2014; Hagar Dighiesh 2014; Shaalan et al. 2018). The current production value of different aquaculture products, periodic growth in value and production quantity in Egypt are highlighted in Table 3 and Figure 1, respectively.

Aquaculture production systems in Egypt

The aquaculture sector in Egypt utilizes different production systems; however, most freshwater aquaculture production in the farms is carried out in semi-intensive earth ponds (El-Gayar 2003; Kleih et al. 2013). Both the intensive and extensive aquaculture production systems are also present and growing; however, semi-intensive and extensive systems are broadly adopted utilizing earth ponds, while concrete tanks are generally used under intensive production system (El-Gayar 2003; Kleih et al. 2013). In the early 1990s, cage aquaculture was introduced in the Nile river catchment for the production of Nile tilapia and silver carp (Cardia and Lovatelli 2007) therefore; floating cages are important aquaculture production system with annual fish production of about 249,385 tons from over 37,000 operational cages across the country (Cardia and Lovatelli 2007; GAFRD 2012).

Extensive systems

Extensive aquaculture, in the form of net enclosures, has been in practice for many centuries and is still active in some regions in Egypt (Shaalan et al. 2018). Extensive net aquaculture is the least economical, and yield from this system ranges from 0.25 to 0.75 tons $ha^{-1} year^{-1}$ (El-Gayar 2003; Shaheen et al. 2013; Soliman and Yacout 2016). Extensive culture system relies solely on naturally occurring food sources in the pond and does not utilize artificial aeration or feeding (Shaheen et al. 2013).

Semi-intensive systems

The semi-intensive production systems are the most practiced aquaculture systems in Egypt contributing about 86% to total aquaculture production with fish yields ranging from 5 to 20 tons $ha^{-1} year^{-1}$ (Shaheen et al. 2013; GAFRD 2014). These systems require the supply of both aquafeed and fertilizers, which are readily available in the market, with protein requirements of the feed ranging from 10 to 30% (Soliman and Yacout 2016). The development of intensive aquaculture systems, however, resulted in a ∼50% decline in fish production from semi-intensive systems in 2012 compared to 2011 production (GAFRD 2014).

Intensive systems

Intensive systems are fast replacing many semi-intensive, and extensive production systems in Egypt to mitigate the dearth of suitable land, stretched water resources as well as economic factors (FAO 2003-2020c). Intensive systems efficiently utilize water and land with yields ranging from 100 to 150 tons $ha^{-1} year^{-1}$ (Shaheen et al. 2013). Adoption of this system of aquaculture production is currently growing in Egypt particularly in the desert area with an annual production of the year 2012 tripling that 2011 (El-Sayed 2007; Alexandratos and Bruinsma 2012; GAFRD 2012). This system requires diets containing high crude protein (>30%) to meet the nutritional demand for the high stocking density of fish, although only 5% of aquafeed available in Egypt contains 30% or more crude protein (El-Sayed et al. 2015). Besides, artificial aeration and water pumps are required in intensive production systems (Soliman and Yacout 2016).

Integrated aquaculture systems in Egypt

Integrated aquaculture systems refer to the utilization of effluent from fish farms to optimize production in other farming systems by maximizing the used water from the fish production system to cultivate crops and animal husbandry (Edwards 1998; Rakocy et al. 2003). Aquaponics and aquaculture cum rice-field farming are the two standard integrated aquaculture practices in Egypt (Shaalan et al. 2018).

A model aquaponic farm was established in 2006 in Cairo by the national institute of oceanography and fisheries (NIOF) to produce tilapia, vegetables and ornamental plants (Essa et al. 2008). Studies conducted on the aquaponic farm showed that fish and crops produced from the farm were healthier, less prone to diseases and increased economic returns (Essa et al. 2008). Aquaponic farms sited in Behira, Sharkia and North Sinai provinces utilize underground water and water from irrigation canals to produce tilapia, and the effluents are reused for vegetable and fruit farm irrigation (Van der Heijden 2012). Aquaponics is developing and essential in Egypt due to a lack of water in the arid areas (Shaalan et al. 2018).

The combination of fish and rice farming is a promising direction in maximizing the efficient utilization of land and water to optimize both fish and rice production and to attain food security, especially in rural areas (Suloma and Ogata 2006). Egypt has the highest rice yield in Africa and the Middle East, with an annual production of about 6 million tons (Sadek 2013; Shaalan et al. 2018). This integrated aquaculture practice has been in existence in Egypt since 1984; however, a leap forward in aquaculture production from rice fields started in 2008 (FAO 2003-2020c; GAFRD 2012). The constraint of freshwater scarcity combined with the high water demands for rice cultivation necessitated the integration of fish production with rice farms. The government incentivized farmers with free supplies of common carp fingerlings to encourage this farming practice in Egypt (Sadek 2013). Rice field aquaculture accounts for about 34,537 tons of fish production annually in Egypt with half of the production being tilapia, and the other half is made up of catfish and common carp (Sadek 2013; GAFRD 2014).

Desert aquaculture

Most of the land area in Egypt lies in the desert, although with a vast reservoir of underground water which accounts for about 20% of freshwater sources nationally. The adoption of desert aquaculture practices, therefore, is an ideal model for the country (Allam et al. 2003; Suloma and Ogata 2006; Sadek 2011; Rothuis et al. 2013). There are about 120 farms established in the Egyptian desert, which contributes around 13,000 tons of aquaculture products annually (Sadek 2011). Cultured species are mainly tilapia, especially the hybrid red tilapia, as they relatively tolerate higher salinity (Stickney 1986; Watanabe et al. 1989; Sadek 2011). Other species cultured are African catfish (*Clarias gariepinus*), carp, mullet, gilthead sea bream, European sea bass and ornamental fish such as koi carp and molly (Bakeer 2006; Sadek 2011). Desert aquaculture could be more sustainable by adopting the recirculating aquaculture system (RAS) to maximize the benefits of effluent water recycling (Martins et al. 2010). Most of the farms in the desert area of Egypt, however, adopt flow-through system (FTS) using the effluent water from the fish farms to irrigate field crops, while only a few farms operate RAS system (Sadek 2011).

Mariculture in Egypt

Egypt has a long coastline that stretches from the north bounded by the Mediterranean Sea (950 km) to the east bounded by the Red Sea (1500 km; Sadek 2000; Bird 2010); however, mariculture is still nascent and not as well developed as freshwater aquaculture (Rothuis et al. 2013; Shaheen et al. 2013). Mariculture operations are concentrated in the north of Egypt, and the Suez Canal with production focused on species such as flat-head gray mullet (*Mugil cephalus*), European sea bass (*Dicentrarchus labrax* – L. 1758) and gilthead seabream (*Sparus aurata*) (Rodger and Davies 2000; Sadek 2000; Rothuis et al. 2013; GAFRD 2014). Shrimp aquaculture is also present but on a limited scale; through extensive farming in Lake

Qarun, semi-intensive ponds in commercial farms and recently around the Suez Canal (Megahed et al. 2013; Rothuis et al. 2013; GAFRD 2014). Mariculture in Egypt contributes around 70% of the total marine fish production in North Africa due to most North African countries relying on wild capture fisheries rather than aquaculture (Rodger and Davies 2000; Shaalan et al. 2018).

Challenges confronting the Egyptian aquaculture industry

Despite the significant rapid development, the aquaculture industry in Egypt has experienced, there are still major challenges and constraints confronting the sustainable expansion of this sector (Soliman and Yacout 2016). The future development of aquaculture industry in Egypt is critically dependent on tackling issues such as conflicts of resource utilization (water and land), energy, quality fish seed production, prices and availability of quality feed, product standardization, marketing and trade as well as provision of enabling environment (policies and framework) amongst others (Soliman 2017).

Fish feed

The availability of quality and reasonably priced feed is a major constraint to the sustainable development of the aquaculture sector in Egypt. Cost of fish feed accounts for about 75% to 85% operating expenses of fish production (Kleih et al. 2013; Dickson et al. 2016). The past few years have witnessed soaring fish feed costs (Macfadyen et al. 2012) due to the importation of ingredients and fluctuations in foreign currency exchange rates (El-Sayed et al. 2015). This has impacted the economic feasibility of production facilities due to farmers purchasing feed on credit, and the continuous increase in the price of feed without proportional increments in the price of fish products, (El-Sayed et al. 2015; Eltholth et al. 2015). Egypt currently has about 73 operational feed mills with an annual production capacity of about 1 million tons of aquafeed annually (Shaalan et al. 2018). Private sector-controlled feed mills contribute about 90% of the total production, while the outstanding 10% comes from the government-owned feed mills (El-Sayed et al. 2015; USDA 2016). Skretting Nutreco with an annual production capacity of 150,000 tons of tilapia feed, besides catfish, sea bass and sea bream aquafeed production, is the largest feed producer in Egypt, followed by Aller Aqua Egypt which produces feed for both freshwater and marine fish (USDA 2016).

Almost 80%–85% of aquafeeds in Egypt are manufactured in pellet form, while about 15%–20% are extruded feeds (Rothuis et al. 2013; El-Sayed et al. 2015; USDA 2016). There is a need for the expansion of extruded feed production in place of pelleted feed to increase FCR and minimize feed wastage (Rothuis et al. 2013).

Fish seed

Fish seed is sourced from two primary sources which are hatcheries and wild catch; however, the challenges of availability and price typically impact on marine fish production more than freshwater aquaculture (Sadek 2000). The distribution of fry is controlled by GAFRD to prevent fraudulent practices; however, government legislation permits the establishment of hatcheries by farmers for the production of carp and sex-reversed all-male tilapia fry due to inability of government-owned hatcheries to keep up with the growing demands for fish seed from farmers (El-Gayar 2003). The first privately-owned hatchery for the production of tilapia fry was established in 1992, and currently, there are over 600 operational hatcheries in Egypt allowing for rapid development of the aquaculture industry (Shaalan et al. 2018). Freshwater fish hatcheries in Egypt have a combined annual production capacity of 411 million fries (GAFRD 2014; Soliman and Yacout 2016), while there are about 73 collection stations of wild-caught marine fry across seven states in Egypt (Rothuis et al. 2013; GAFRD 2014). The critical success factor for the sustainable operation of hatcheries include, but are not limited to, the capability to produce sex-reversed tilapia fingerlings at favorable sizes, different seasons and salinity tolerance (Stickney 1986; El-Gayar 2003).

Tilapia hatcheries are more functional in the summer due to favorable weather for spawning and fry production although some hatcheries adopt heating systems to be operational all year round albeit with increasing operational expenses (Nasr-Allah et al. 2014). Hatcheries adopt different heating systems, including biogas; however, the most cost-effective method is the use of hapas covered by greenhouses (Sadek 2011; Nasr-Allah et al. 2014).

Land and water availability

Government legislation permits the setup of fish farms on barren lands which are considered unsuitable for other activities such as agriculture and tourism, due to the competing demand for already scarce land and water resources in Egypt (GAFRD 2014). Also, the utilization of the River Nile for aquaculture activities is prohibited by the current laws, and the permit to set up a fish farm has to be issued by the Ministry of Agriculture (El-Gayar 2003; Rothuis et al. 2013; Hebisha and Fathi 2014). Water problems caused by irrigation channels are usually subjected to agricultural seasons, water level variations all through the year and susceptibility to contamination with agricultural pesticides (Eltholth et al. 2015). Lands that are unsustainable for crop production are often used for fish farming, to prevent competition between freshwater aquaculture and contemporary field agriculture (El-Gayar 2003; Suloma and Ogata 2006; Hebisha and Fathi 2014). Mariculture development is also confronted with the growth of tourism and urbanization along the coasts of the Mediterranean and Red Sea (El-Gayar 2003). The desert aquaculture, therefore, could act as a promising substitute with minimal competition and the future of sustainable aquaculture due to the vast desert land of Egypt.

Diseases

Fish diseases caused by parasites, bacteria, fungi and viruses are responsible for mortalities and substantial economic losses in aquaculture operations (Fathi et al. 2017). Pathogenic conditions severely affect the FCR and final body weight of post-infection recovered fish asides mortalities. Fish mortalities linked with infectious diseases are prevalent in tilapia in the summer months of June to October yearly, resulting in about USD 100 million economic losses (Fathi et al. 2017). Parasites are the most prevalent pathogens responsible for about 80% fish disease condition in aquaculture farms (Shaheen et al. 2013). Infectious diseases caused by different strains of bacteria also occur in fish with resultant mortalities as compared to parasitic infections were also reported in Egyptian farms (Al-Shamy 2010; Aly 2013; Shaheen et al. 2013; Abdelsalam et al. 2017). There is insufficient information about viral infections and spread in Egypt, probably due to the lack of established surveillance program for monitoring and controlling viral infections in fish.

Aquaculture marketing and trade

The marketing of fish in Egypt is a simple and efficient system controlled by few big wholesalers who fix the market price for fish in response to forces of demand and supply (Soliman and Yacout 2016). Farmers are usually at liberty to sell their fish directly to retailers or via wholesalers (Soliman and Yacout 2016). There are approved wholesale markets, where farmers can bring and auction their fish daily in all major cities (El-Gayar 2003). Aquaculture traders/wholesalers play a significant role as financiers in providing credits to many fish farmers and generating an income of $\pm$3%–6% as sales commission on fish sales on behalf of the farmers (Soliman and Yacout 2016). Annual farm production usually gets landed in the market within short periods and are mostly distributed and consumed in the fresh state as the fish processing sector in Egypt is still very nascent (Soliman and Yacout 2016).

Egypt is yet to attain self-sufficiency and is a net importer of fish products, despite the significant growth in aquaculture production (GAFRD 2014). Fish imports grew from 259,000 tons in 2007 to 335,000 tons in 2012 due to strong growth in annual per capita consumption of fish from 8.5 to 15.5 kg within the same period (GAFRD 2012, 2014).

Aquaculture policies and framework

The Ministry of Agriculture and Land Reclamation in Egypt is saddled with the task of managing the fisheries and aquaculture sector while management and policy implementation is assigned to the General Authority for Fish Resources Development (GAFRD 2014). GAFRD, which is a subsidiary of the Ministry of Agriculture and Land Reclamation, is the organization responsible for the planning and controlling of all activities that concern fish production (Macfadyen et al. 2012). The current policy for the development of aquaculture and fisheries industries as drafted by GAFRD aims at the following (Goulding and Kamel 2013):

I. Increase the return on investment on fishery/aquaculture resources through environmentally compatible systems.
II. Attain annual production of 1.5 million tons (an annual per capita of local fish production, which amounts to 16.5 kg) in 2017 to maintain per capita of fish production as a result of the growing population.
III. Improve fish products from various sources that will meet the standard of international markets.
IV. Support marine aquaculture.

Table 4. Aquaculture production quantity in Nigeria by species in 2013.

Fish species	Production quantity (tons/year)
Catfish	233,605
Tilapia	21,680
Carps	23,421
Total	278,706

Adapted from FAO (2007-2020); Cai et al. (2017).

The strategy of GAFRD aims to boost the productivity of freshwater fish production; however, the aquaculture policies of Egypt due to the limitation of freshwater resources are currently geared more toward promoting mariculture of species such as mullets, groupers, meagers, soles, perches and invertebrates such as shrimps, sea cucumbers and other shellfish species (Soliman and Yacout 2016).

Fish farmers need approval from the Egyptian Environmental Affairs Agency (EEAA) and submit an Environmental Impact Assessment (EIA), to obtain a permit. In practice, EIA is, however, rarely conducted for aquaculture production, and not required before the commencement of aquaculture production, except for mariculture production, where inland waters rules are not applicable but EEAA laws (Nugent 2009).

Aquaculture in Nigeria

Nigeria is the second-largest aquaculture producer in Africa with a production output of about 300, 000 tons annually and largely dominated by catfish culture (Ozigbo et al. 2014; FAO 2016, 2018). Aquaculture production began in Nigeria over five decades ago (Olagunju et al. 2007); however, it has not been able to bridge the gap between domestic consumption and production output (Ozigbo et al. 2014). Aquaculture development in Nigeria was primarily driven by socio-economic objectives such as supplementary income generation, improvement of nutrition in rural locations and employment creation, until recently when the perspective of aquaculture was changed and tailored to meet domestic shortfalls in fish supplies to reduce fish importations (Ozigbo et al. 2014). Fish accounts for about 40% of animal protein consumption, with a per capita fish consumption of 13.3 kg (WorldFish 2018).

Aquaculture production and value

According to Catfish Association of Nigeria (CAFAN), Nigeria produced 370,000 metric tons of fish from aquaculture systems in 2016 valued at over USD 1.3 billion (BusinessDay 2017). Aquaculture production accounts for about 34% of the total national fisheries production, employs about 475,000 people and contributes 4.5% to GDP (BusinessDay 2017; WorldFish 2018).

Cultured fish species in Nigeria

The Nigerian aquaculture industry is characterized by the culture of African catfish, tilapia, carp and *Heterotis niloticus* G. Cuvier 1829 however, the African catfish species (*Clarias* spp. and *Heterobranchus* spp.) (Table 4) are the most cultured species due to their hardiness, wide acceptability and high market value (Oyakhilomen and Zibah 2013; Ozigbo et al. 2014). These species are usually reared to acceptable market size within a culture period of 4–9 months, depending on the adopted production system (Adewumi 2015). The success story of the aquaculture industry in Nigeria is primarily hinged on catfish farming (Adewumi and Olaleye 2011) and accounts for over 80% of aquaculture production in Nigeria (Anetekhai Agenuma 2010).

The production of catfish species in Nigeria has evolved rapidly over the years since 1985, with the advent of flow-through tank systems and RASs leading to a significant increase in production output of fish per unit area across the country (Adewumi 2015). This study was restricted to present the total annual aquaculture production output and the estimated percentage production output of the dominant aquaculture species, due to lack of data on specific production outputs of each aquaculture species cultured in Nigeria.

Freshwater aquaculture production systems in Nigeria

The advent and the development of hatchery technique for fingerlings (catfish seedlings) production of *Clarias* species and their hybrids resulted to catfish becoming the dominant aquaculture fish species produced by tonnage in Nigeria (Anetekhai Agenuma 2010). Aquaculture production involves two major stages of production:

1. Fish hatchery—production of fingerlings and juveniles.
2. Pond culture—earthen/dug-out, concrete tanks, cage/pen culture, fiber tanks, intensive recirculation and FTSs.

Fish hatchery

Fish hatchery setup in Nigeria typically is intensive systems comprising of overhead tanks, series of flow-through hatching troughs for incubation and hatching of fertilized eggs, and flow-through tanks for raising fry/hatchlings to fingerlings (Adewumi 2015). Hatcheries in Nigeria are mainly FTSs which account for 99%, while RAS account for 1% of hatchery operations (Anetekhai Agenuma 2010). Hatchery operations entail series of breeding activities which include the collection, selection and manipulation of brood stocks for spawning or egg stripping, and from the rearing of hatchlings to fingerings stage which usually spans a minimum of four weeks (Akankali et al. 2011).

Grow-out systems

This is the grow-out phase which entails rearing of fingerlings/juveniles to table size fish in different water holding systems (Adewumi and Olaleye 2011). Pond aquaculture in Nigeria is usually carried out in systems such as earth ponds, concrete ponds, fiber tanks, cages and pens, RAS and other watertight containers that can hold sufficient water volume to sustain fish production (Anetekhai Agenuma 2010).

I. **Earthen ponds:** These are excavated earth resulting in a water-holding depression, and it is a conventional aquaculture production system adopted in areas with a high water table (Anetekhai Agenuma 2010). Earthen ponds are usually impounded after preparatory processes (desilting, netting, liming, fertilizing) with water from underground seepage, reservoir, borehole and rainfall, after which fish are stocked and fed with pelletized or extruded feed from fingerlings/ juveniles to table size (Anetekhai Agenuma 2010). Production period in earth ponds spans between 5 and 6 months with good feeding and water quality management (Anetekhai Agenuma 2010).

II. **Concrete ponds:** Concrete ponds are similar to earth ponds except the walls and floor are made of concrete or building blocks filled with cement mix (Ozigbo et al. 2014). Concrete ponds are mostly surface tanks and are well equipped with the water inlet and outlet drain for ease of operation (Anetekhai Agenuma 2010). Concrete ponds are intensive systems with higher stocking density than earth ponds and require good water exchange (Emmanuel et al. 2014). Most concrete ponds in Nigeria are operated as a semi flow-through or flow-through ponds to improve water quality parameters during the culture period (Emmanuel et al. 2014).

III. **FTSs:** This system is also referred to as a raceway, and it is one of the earliest systems utilized in inland aquaculture (Ozigbo et al. 2014). The system generally has tanks made of concrete or plastic fitted with an inlet and outlet pipes that allow water to flow in and drain out without recirculation (Anetekhai Agenuma 2010; Ozigbo et al. 2014). Continuous water flow is sustained within the system to maintain the required water quality parameters required to culture fish at high stocking density (Anetekhai Agenuma 2010). FTSs are commonly used in Nigeria in hatcheries for the production of catfish fingerlings (Anetekhai Agenuma 2010).

IV. **RAS:** This is a closed highly intensive system where water is pumped into the fish tank via mechanical and biological water filtration systems and reuse, thus capable of stocking about 200 to 400 catfish.m^2 (Anetekhai Agenuma 2010; Ozigbo et al. 2014). RAS guarantees optimum rearing conditions as water is exchanged continuously (Anetekhai Agenuma 2010; Ozigbo et al. 2014). RAS is highly technical and requires high-end management, equipment and constant power supply to maintain optimal operating conditions (Masser et al. 1999). The setup and operating cost of RAS can be expensive; therefore, economically not feasible to grow low-value fish (Ozigbo et al. 2014). Erratic power supply and high cost of operating power generators make the operation of RAS non-viable in Nigeria; however, there are a few farms that utilize RAS for fingerlings and table fish production of catfish (Anetekhai Agenuma 2010; Ozigbo et al. 2014).

V. **Cage culture:** These are enclosures made of synthetic netting and frames suspended in natural water bodies with the aid of buoys and anchors for table size fish production (Anetekhai Agenuma 2010). Cage culture is an emerging fish production system in Nigeria, and it is capable of significantly increasing the annual aquaculture production as more investments are being channeled toward cage culture (Obwanga et al. 2018). Nigeria is well-endowed with natural water bodies such as rivers, lakes and estuaries, which are suitable for cage culture (Obwanga et al. 2018). According to press statements released by commissioners of agriculture, Nigeria produced over 150 tons of fish from cage culture systems in 2017 (Obwanga et al. 2018).

Aquaculture production models in Nigeria

The prevalent aquaculture production models practiced in Nigeria include, but are not limited to;

i. ***Backyard/cottage farming:*** This aquaculture production model was promoted to encourage families to be food sufficient and earn extra income by building and operating fishponds in their house using basic production systems that require minimal skills and low-cost materials such as waterproof materials (Anetekhai Agenuma 2010). Homestead catfish farming is prevalent in Nigeria and contributes significantly to the total yearly aquaculture output (Anetekhai Agenuma 2010).
ii. ***Integrated farming***: This is usually the integration of fish rearing facilities with the poultry production system and crop production (Anetekhai Agenuma 2010). Maggots generated from poultry feacal droppings are channeled into catfish ponds as supplementary feed (Anetekhai Agenuma 2010). Also, effluent from catfish pond is channeled into leafy vegetables, plantain, pineapple, maize and rice field as organic fertilizer for good plant yield (Anetekhai Agenuma 2010).
iii. ***Hatcheries:*** Few farms in Nigeria run commercial fingerlings production solely and maintain viable brood-stock bank for all-year-round production of fingerlings/juveniles (Anetekhai Agenuma 2010). Sizes of catfish fingerlings range from 3 to 5 g per fish, while juveniles are from 8 to 10 g per fish and are reared intensively for 8 to 12 weeks from the point of hatching (Anetekhai Agenuma 2010). Hatchery operators generally supply production farms with fingerlings and juveniles (Anetekhai Agenuma 2010)
iv. ***Table fish production:*** This is a standard model of commercial fish production in Nigeria (Anetekhai Agenuma 2010). The farmers acquire either fingerlings/juveniles from a known hatchery and rear to table size in production ponds (Anetekhai Agenuma 2010).
v. ***Hatchery and table fish production:*** Most big commercial fish farms in Nigeria operate a functional hatchery which produces the fingerlings or juveniles which are stocked and reared in earth or concrete production ponds for a period ranging from 4 to 6 months to attain acceptable market size while excess fingerlings/juveniles produced are sold to production farms (Anetekhai Agenuma 2010). The market size of frozen or live catfish in Nigeria varies according to the region; however, it ranges from 1 to 3 kg, while the size of wet fish to be smoked are between 0.35 to 1 kg (Anetekhai Agenuma 2010).
vi. ***Public/private/cooperative partnership***: This farming model is based on setting up a central farm funded by the government, but managed by the private sector that services a network of satellite farms through the provision of fish production inputs such as juveniles and feed as a credit (Anetekhai Agenuma 2010). The satellite farms produced table size fish from the inputs supplied and payback with fish or cash after the production cycle (Anetekhai Agenuma 2010).

Mariculture in Nigeria

Nigeria has a coastline stretch of 853 km from the south-west end of Badagry Lagoon to the southeastern tip of Cross River, near Calabar (Coche 1982). It has an unexploited 729,000 hectares of land that is suitable for mariculture (Sylvanus and Gao 2007; Amosu et al. 2013); however, the culture of marine species in Nigeria is almost non-existent as freshwater catfish aquaculture dominates the industry (Anetekhai Agenuma 2010). Nearly all the aquaculture hatcheries in Nigeria are designed and situated to produce freshwater species, thereby, neglecting the development of numerous coastal and marine species with aquaculture potential (Anetekhai Agenuma 2010). The absence of mariculture has been linked to many factors which include; pollution due to densely distribution of anthropogenic activities (oil and gas exploration, sand mining, maritime activities and industrialization) in coastal areas; very shallow continental shelf; inadequate technical know-how on the hatchery management practices of the indigenous marine/coastal fish species and lack of political will due to preference for oil and gas exploration (Amosu et al. 2013).

Challenges confronting the aquaculture industry in Nigeria

Nigeria has an estimated population of 201 million people according to the 2019 data of the United Nations with a projected annual fish demand of 3 million tons and local production of 1.1 million tons in 2017 (Vanguard 2017). There is thus a huge gap of almost 2 million tons of fish demand which is partly bridged by importation (Vanguard 2017). Despite the huge aquaculture potentials and development in freshwater aquaculture, Nigeria is yet to be able to bridge the gap between domestic fish production and consumption (Adedeji and Okocha 2011) due to combination of prevailing challenges confronting the aquaculture sector. Some of the challenges are plaguing the aquaculture sector including but not limited to high-cost fish feed, the supply of quality breed of fingerlings from reliable hatcheries, availability of suitable land and reliable water source, disease management, creation of a favorable environment to drive accelerated development and marketing of aquaculture products (Adedeji and Okocha 2011).

Fish feed

High and soaring cost of fish feed has been a major challenge confronting the economic viability of aquaculture development in Nigeria (Udoh and Dickson 2017). The production of high-quality aquaculture feed has also been a major constraint hindering the growth of the aquaculture industry in Nigeria (Udoh and Dickson 2017). Fagbenro and Adebayo (2005) reported that feed account for about 60% of operational cost in Nigeria. The cost of feed currently accounts for about 80% of production cost due to currency devaluation, fluctuating exchange rate and inflation; thus increasing the cost of fish production (Udoh and Dickson 2017). The aquaculture industry in Nigeria largely depends on the importation of both manufactured feeds and feed ingredients due to insufficient local production and competitive use of ingredients with other livestock feeds (Adedeji and Okocha 2011). The importation of feeds and ingredients exposes the industry to increase in prices due to the rising exchange rate (Adedeji and Okocha 2011).

Some interventions such as input subsidies, credit facilities, pricing policies and market liberalization were put in place, to meet the demand for aquafeed and increase the production output of the aquafeed industry (Udoh and Dickson 2017). The production output, however, is still very low and unable to meet the demand of the aquaculture industry (Udoh and Dickson 2017).

Nigeria has the highest number of feed mills in Sub-Saharan Africa albeit, dominated by small-scale operators whose production capacity range from 0.5 to 3 tons per hour and account for about 60% of local aquafeed production (Fagbenro and Adebayo 2005).

Fish seed

The supply of fish seed is mostly sourced from hatchery production under a controlled environment, as fingerling collection from the wild is highly unreliable and unsustainable for aquaculture (Bondad-Reantaso 2007). Numerous fish hatcheries have been established in Nigeria, with most of them located in the South-Western part of the Country (Bondad-Reantaso 2007). Availability of quality fish seed produced from high-quality brood stock with known genetic composition and performance is required (Adewumi 2015). The demand-supply gap for fish seed is considerably huge (Omoyinmi and Ezeri 2011) as Nigeria currently requires at least 1 billion fingerlings/seeds annually to meet market demand for table size fish while it barely produces about 55 million fingerlings from all available sources (Atanda 2007). There is, therefore, a pressing need to address the challenges of inadequate production of high-quality brood-stock and seed encountered by the aquaculture industry in Nigeria (Adewumi 2015). Besides, there is a need for the Nigerian aquaculture industry to explore advanced technologies of breeding to develop improved strain and quantities of fish seed. Successful completion of ongoing research work on the cryopreservation and viability of the milt of Clarias is, therefore, expected to address the perennial shortage of male catfish brood-stock during the dry season, slaughtering of the male brooder for milt extraction and eventually boost commercial production and availability of fingerlings/seeds all-year-round (Adewumi 2015). The lack of standardization of hatchery practices in Nigeria due to the nonexistence of institutionalized quality control processes results to sharp practices by hatchery operators in terms of seed quality, sizes and price which often affects farmers production output and profitability (Adewumi 2015).

Land and water availability

Land is an important resource which is readily available for production in Nigeria; however, land availability is a major constraint to aquaculture development in the southeastern part of Nigeria due to competitive use of land (Ugwumba and Chukwuji 2010; Adedeji and Okocha 2011). The location of available land often determines the utilization for aquaculture and production systems adopted by fish farmers (Adedeji and Okocha 2011). Fish farms located in swampy areas with access to ample water usually adopt an earth pond system while other farmers convert available spaces in their homes into ponds

(Adedeji and Okocha 2011). Availability of land for aquaculture production in Nigeria involves the complexity of interactive factors such as land tenure system, population, technology level and competitive use of land, therefore, limiting the amount of land available for aquaculture (Ojo and Afolabi 2003).

Water pollution as a result of dredging, oil exploration and discharge of toxic industrial effluents into water body has been responsible for mass fish mortality thus severely impacting fisheries production and aquaculture development especially in the southeastern and Niger-Delta region of Nigeria (Olowosegun et al. 2005; Akanni and Akinwumi 0008; Ugwumba and Chukwuji 2010).

Diseases

The awareness level of disease impacts on the aquaculture industry in Nigeria is currently low (Adedeji and Okocha 2011). The economic importance of fish diseases largely remains a concern to the aquaculture industry (Adedeji et al. 0002; Adeyemo et al. 0006; Kolndadacha et al. 2007). *Clarias gariepinus* is a highly resistant and valued freshwater fish species reared in Nigeria, thus the need for research on its vulnerable diseases and public health implications (Adedeji and Okocha 2011).

The shortage of skilled and experienced aquatic veterinarians with knowledge of aquaculture disease prevention, treatment and control complicated by lack of fish diseases diagnostic laboratory has been a major limiting factor to aquaculture development in Nigeria due to inadequate teaching of fisheries and wildlife medicine in the veterinary medicine curriculum in Nigerian universities (Adedeji and Okocha 2011).

High-level management practices which involve maintenance of good water quality, hygienic practices and disease-resistant species are, therefore, being employed by commercial farms to prevent or minimize the incidence of disease outbreaks (Adedeji and Okocha 2011).

There has been a surge in the utilization of veterinary drugs, chemical and biological controls in the aquaculture industry due to the rapid development of aquaculture production in the past two decades, and increase in fish and shellfish diseases (Adewumi 2015).

Aquaculture marketing and trade in Nigeria

Catfish, which is the predominant aquaculture fish in Nigeria, is primarily traded and consumed fresh in the south (Veliu et al. 2009). Smoked catfish is preferred in northern regions of the country, although there is also a growing production and demand for smoked catfish in the southern markets (Cocker 2014). The supply chain of catfish in Nigeria is primarily controlled by wholesalers who determine the price per size range of fish in response to the prevailing macroeconomic conditions (Cocker 2014). Catfish are commonly distributed and sold live from the farm gates to designated fish markets in most cities and towns nationwide, where the fish are sold to restaurants, processors and final consumers (Igoni-Egweke 2018).

Several processing methods such as smoking, drying and freezing are used to increase the shelf life of catfish in Nigeria as a result of its high perishability. Smoking, the most feasible processing method and widely acceptable product form (Eyo 1999), is very affordable, inhibits microbial spoilage and increases the organoleptic properties of the final product (Omobepade et al. 2018). Smoked catfish are commonly packed in transparent plastic wrappers and are widely distributed across the country as well as exported to neighboring countries and overseas (Igoni-Egweke 2018).

Nigerian aquaculture policies and framework

There is no specific legislation on aquaculture nationally in Nigeria; however, the Inland Fisheries Decree (1992) empowers the Minister in charge of fisheries matters to regulate the licensing of enclosures such as pens and cages (FAO 2005-2020b).

Institutionally, the Federal Department of Fisheries (FDF) under the Federal Ministry of Agriculture and Natural Resources is the competent authority saddled with the responsibility of fisheries management, preparation of policies, development of fisheries programs and provision of technical support to State Departments of Fisheries (SDF). The SDFs, in turn, provide support to Local Government Authorities (Ayala-Tafoya et al.) on fisheries and aquaculture matters (FDF 2012). The Nigerian Institute for Oceanography and Marine Research (NIOMR) and the National Institute for Freshwater Fisheries Research (NIFFR) are majorly responsible for fisheries and aquaculture research, while aquaculture training is certified by the African Regional Aquaculture Center (ARAC; FAO 2005-2020b).

Aquaculture used to be a developmental program in which the government is directly involved in policy formulation, training, infrastructure development,

Table 5. Aquaculture production quantity in Uganda by species in 2013.

Fish species	Production quantity (tons/year)
Catfish	49,517
Tilapia	47,841
Carps	705
Total	98,063

Adapted from FAO (2004-2020); Cai et al. (2017).

inputs and products production (FAO 2005-2020b). The current policy considers aquaculture as an industry in which production at all levels of the value chain is driven by the private sector, while the government creates enabling environments (Anetekhai Agenuma 2010).

Aquaculture in Uganda

Aquaculture started in Uganda in 1941 with the introduction of carp into the country by the colonial authorities (MAAIF 2012). Aquaculture production grew from 15,000 to 118,000 tons from 2005 to 2015 due to interventions of government and developmental partners such as FAO (FAO 2004-2020). African catfish (*Clarias gariepinus*) and Nile tilapia (*Oreochromis niloticus*) and are the two predominantly cultured fish species in Uganda with production mainly made up of catfish (60%) while Nile tilapia accounts for 40% (FAO 2004-2020). Nile tilapia is widely cultured among the Ugandan fish farmers owing to its prolificacy and tasty appeal (Cai et al. 2017). African Catfish production has been growing and notably common among farmers in the Eastern region as a result of perfection in breeding technology among hatchery operators (Mwanja 2007). Fish represents approximately 63% of protein consumption in Uganda, with annual per capita consumption of fish estimated at 12.5 kg in 2013, higher than the African average of 10.1 kg (FAO 2004-2020).

Aquaculture production and value

Uganda is the third-largest aquaculture producer in Africa, after Egypt and Nigeria supplying fish and fishery products in the form of feed, fish seeds, aquaculture inputs and technical expertise to neighboring countries mainly Kenya, Congo and Rwanda (FAO 2004-2020; Safina et al. 2018). Uganda is the second largest aquaculture producer in Sub-Saharan Africa after Nigeria, with production increasing from about 800 tons in 2006 to 103,737 tons in 2018 (FAO 2004-2020). The aquaculture industry in Uganda directly employs about 24,434 people (FAO 2004-2020). Fish is a high-value commodity and contributes 3% to the national GDP of Uganda (Safina et al. 2018).

Aquaculture fish species in Uganda

Nile tilapia (*Oreochromis niloticus*), until recently used to be the most cultured fish species across Uganda due to its taste, easy reproduction and growth performance, however, the North African catfish (*Clarias gariepinus*) production has recently surpassed the Nile tilapia production as common aquaculture species (FAO 2004-2020). The characteristic rapid growth rate of catfish and ability to feed on the available organic matter available at household level makes it widely acceptable amongst Ugandan fish farmers (MAAIF 2012). Catfish is predominant in all the water systems in Uganda, particularly water catchments linked with swamps (FAO 2004-2020).

The common carp (*Cyprinus carpio*) is the third most cultured aquaculture species in Uganda; however, insufficient fingerlings production, inadequate extension services and unstable post-independence government policies hindered the growth of carp aquaculture. Carp culture is still currently abundant in some parts of Uganda, however, at a low scale of production (FAO 2004-2020).

Other aquaculture species that were introduced and being cultured in the country are the giant river prawn (*Macrobrachium rosenbergii* - De Man 1879) and the red swamp crayfish (*Procambarus clarkii*). The giant river prawn production in the country is mainly dependent on regular larvae importation while the red swamp crayfish population is well distributed in Lake Bunyonyi and at Kajjansi Aquaculture Research and Development Center (FAO 2004-2020). Due to limited available data on the current production outputs of each aquaculture species cultured in Uganda, this study presents the aquaculture production output of the dominant aquaculture species documented for 2013 (Table 5).

Freshwater aquaculture production systems in Uganda

Aquaculture productions in Uganda were carried out mainly using pond culture systems, until recently that other forms of fish production systems such as cage culture system are emerging due to the advent of commercial fish farms (FAO 2004-2020).

Pond systems

Fish farmers mostly adopt intensive and semi-intensive pond culture systems in almost all districts of Uganda (Isyagi et al. 2009). The intensive pond production system utilizes smaller and deeper earth ponds which are used mainly to culture sex-reversed Nile tilapia (Mbowa et al. 2016b). Major factors that inform the decisions of fish farmers on the size of ponds are production costs, recommendations by extension personnel and land size (Isyagi 2007). Due to the drive for the commercialization of aquaculture production in Uganda, average pond capacity has increased to 500 m^2 per fishpond (Rutaisire et al. 2017).

Tank systems

Tank systems were first introduced in Uganda in the early 1990s to produce European eel (*Anguilla anguilla*) on private farms (Isyagi 2001). Circular and rectangular tanks are currently being used for spawning and seed production by the catfish hatcheries (Rutaisire et al. 2017). Aquaculture tanks of various designs are used generally in modern hatcheries for induced breeding of fish. Most of the hatchery setups typically are made up of breeding tanks, larvae rearing tanks and holding tanks (Rutaisire et al. 2017). Tank systems are also employed for intensive Nile tilapia and catfish productions using underground freshwater system (Mbowa et al. 2016b). Tank capacity is dependent on fish management practices, production cost, water quality maintenance and space utilization (Rutaisire et al. 2017).

Cage systems

Cage culture system in Uganda emerged in 2006 in Lake Victoria and Kyoga as an alternate system to boost aquaculture production and still in its nascent phase (Blow and Leonard 2007). The continuous decline in capture fisheries from Ugandan lakes and rivers have necessitated the development of cage aquaculture operations promoted by the Ugandan Government as a development priority and supported by development partners such as the Belgian Technical Corporation (BTC), European Union (EU), non-governmental organizations, individual farmers, and youth groups (Kifuko 2015). The most commonly adopted cage system is the low-volume high density (LVHD) cages of 8 m^3 with a stocking density of 200–400 fingerlings m^{-3}, depending on the depth and flow rate of water (Rutaisire et al. 2017). Cage system is used predominantly in growing hatchery-produced fry of Nile tilapia (*Oreochromis niloticus*) using the pelleted aqua feed. Cage culture is adopted currently by the major stakeholders in the aquaculture sector such as research institutions, local governments, private investors and donor agencies (Mbowa et al. 2016a; Rutaisire et al. 2017).

The Nile River in Uganda provides favorable temperature and good water quality parameters; therefore, providing suitable opportunities for cage culture development and job creation (Blow and Leonard 2007). The productivity of cage culture is substantially dependent on management practices, and ranges from 5 to 35 kg fish m^{-3}. The government policy of restricting the number of cages has been a significant factor affecting operational cages in Uganda (Mbowa et al. 2016a).

Challenges confronting the aquaculture industry in Uganda

Several challenges such as marketing, transaction costs, availability of feed, limited supply of fingerlings, limited availability of suitable land, fish diseases management, regulatory framework and policies amongst other factors of production, similar to those confronting the development of aquaculture in other Sub-Saharan African countries are the limiting factors challenging the growth of aquaculture in Uganda (Cai et al. 2017).

Fish feed

The quality and quantity of aquafeed production level in Uganda are not sustainable to address the demand for fish feed (Olwo 2009). The fish feed industry is solely driven by private producers whose uneven geographic distribution and production operations are grossly inadequate to meet the local aqua feed demand (Mbowa et al. 2016a). Due to near absence of government regulation on fish feed quality assurance, the standard of locally manufactured fish feed constitutes a major limiting factor to the development of aquaculture as fish farmers are not guaranteed of the quality of feed being used (Rutaisire et al. 2017).

Fish seed

One of the major constraining factors limiting the development of the aquaculture industry in Uganda is inadequate fry production due to a shortage of fish fry hatcheries in the country (Jagger and Pender

2001). The government established fish hatcheries became moribund and non-operational due to poor management resulting in a dearth of fingerlings supply (Mbowa et al. 2016a). The country continued to experience a deficit in the production of fish seed due to deficient production technologies used in hatcheries coupled with lack of standardization of production practices between research institutions and commercial hatcheries, (Mwanja et al. 2015). The drive to develop the aquaculture sector coupled with diversification of aquaculture production systems resulted in a rapid increase in demand for fish seed. The supply of fingerlings, however, is greatly hindered by inadequate operational hatcheries and low productivity of existing hatcheries (Mwanja et al. 2015).

Land and water availability

Fragmentation of land and decreasing size of farms is a common occurrence in most parts of Uganda due to limited land availability and competitive demand for land (Jagger and Pender 2001). The average farm size is about two hectares, whereas, in some densely populated upland regions such as Kabale, the average size of farms is smaller than two hectares (Kisamba-Mugerwa 2001). Wasteland and other lands with a low cost or lack opportunity cost, including gullies and ditches that can support fishponds may be appropriate for fish farming (Jagger and Pender 2001). The challenge facing aquaculture development in land constrained areas with a high opportunity cost may have been addressed by the development of aquaculture parks in areas including wetlands, lakes and rivers as proposed by the government. The attempts at creating enabling environment for the development of aquaculture sector, however, was met with weak governance capacity in securing site tenure, accountability and management (Jagger and Pender 2001; Dickson et al. 2012; Rutaisire et al. 2017).

In trying to mitigate against the impact aquaculture activities on sustainability and biodiversity of wetland, the government opted to encourage small scale aquaculture as a sustainable means of wetland utilization; however, the permits fees for aquaculture activities in wetlands are beyond the affordability of many small-scale farmers (Jagger and Pender 2001).

Diseases

The policy instrument for the management and development of fisheries and aquaculture in Uganda gives limited attention to fish health management while the legal provisions for fish diseases control do not have management provisions for effective control and management (Akoll and Mwanja 2012).

The emergence of medium and commercial scale aquaculture contributed to the outbreak of fish diseases resulting in mass mortalities being recorded in hatcheries and grow-out systems (William and Kim 2015). Assessment of some fish farms and review of aquaculture regulatory frameworks of Uganda revealed significant lapses in biosecurity from the point of fish health management, farm management practices, inputs and products quality assurance, farmer organization and education, technical capacity, aquaculture environmental impact management, enforcement of aquaculture regulations and research (William and Kim 2015). Previous studies on fish health mostly focused on wild fish parasites while very little information is available on pathogens and diseases of aquaculture species (William and Kim 2015). Diagnostic facilities for fish are still very elementary with control and prevention plans existence barely in practice (William and Kim 2015).

Aquaculture marketing and trade in Uganda

The aquaculture industry in Uganda is grouped into three areas: smallholder fish farms, medium-scale commercial fish farms and large-scale commercial fish farms. The smallholder farmers target the local fish markets, while large-scale commercial farms focus on regional markets from neighboring countries (Dickson et al. 2012). The rapid decline in catches from the wild seems to portend a significant potential for the development of aquaculture products market in Uganda (FAO 2004-2020). The current aquaculture production can barely sustain a steady market; however, the demands from various retail stores involved in the distribution of foodstuffs have considerably changed production patterns, supply and distribution of aquaculture products (Rutaisire et al. 2017). Access to finance at an affordable interest rate is a major constraint hindering production capacity due to the high level of investments needed to meet the target market demands (Jagger and Pender 2001).

Ugandan aquaculture policies and framework

The Department of Fisheries Resources (DFR) under the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) is the competent authority in Uganda saddled with the responsibility of inspection, certification and approval of aquaculture

Table 6. Aquaculture production share and value by subsectors in South Africa in 2013 (Britz and Venter 2016).

Subsectors/species	Production share (%)	Production share (tons)	Value (%)	Value ($)
Trout	31.7	1568	16.3	7,856,600
Abalone	30.6	1513	76	36,632,000
Mussels	23.2	1147	2.9	1,397,800
Others	14.5	717	4.8	2,313,600
Total Marine Species	62.2	3076	82.2	39,620,400
Total Freshwater Species	37.8	1870	17.8	8,579,600

establishments and allied practices (FAO 2004-2020). The overall strategic goal of the fisheries sector is to enhance sustainability in fish and fisheries products production and utilization through well-managed capture fisheries and the promotion of aquaculture (MAAIF 2012). The DFR is mandated to promote, guide and support public and private sector partners involved in fisheries and aquaculture activities in sustainable development as well as responsible for setting and enforcing regulations and standard for practices on fisheries and aquaculture (MAAIF 2012). The DFR also provides services such as technical back-up associated with fisheries and capacity building for Local Governments; information provided for all stakeholder groups; creation of funding strategies for sector development; ensure sustainable resource utilization through good fisheries policy and equitable legal basis for sustainable fisheries and aquaculture management (FAO 2004-2020).

Aquaculture in South Africa

Aquaculture started in South Africa when attempts were made with mariculture of indigenous oysters in 1673 and 1676; however, commercial operations were not successful until 1948 (FAO 2010-2020b). Abalone (*Haliotis midae* L. 1758.) aquaculture which started in the early 1990s is till date the leading mariculture sub-sector in South Africa, with most farms concentrated in the Overberg area of Western Cape Province (DAFF 2018a).

Rainbow trout (*Oncorhynchus mykiss*) farming is the oldest freshwater aquaculture subsector in South Africa (DAFF 2018b). The first batch of Rainbow trout seeds was imported into the country in 1896, while dry pelleted feeds were introduced in 1956 (Hecht and Britz 1990). Rainbow trout are produced mainly in the Western Cape and Mpumalanga provinces with a production of about 1000 tons recorded in 2010 (Hecht and Britz 1990).

South Africa has conducive environmental conditions for the development of the aquaculture sector as well as enormous opportunities for the commercial production of various cultured species. The aquaculture sector has, however, underperformed compared to its potentials and therefore, minimally contributes to the fisheries products and GDP of the country (FAO 2010-2020b). Aquaculture in South Africa compared to Egypt, Nigeria, Uganda and the rest of the world, relatively remains a small industry.

Aquaculture production and value

South Africa occupies the tenth position amongst the top 10 aquaculture producing countries in Africa in 2018 and accounts for 0.28% of total food fish aquaculture production in Africa (FAO 2010-2020b; IDC 2015). The aquaculture industry in South Africa recorded a total production (excluding seaweed) of 5418 tons in 2015 valued at R 696 million (US$ 48.2 million), with mariculture subsector accounting for 3592 tons (72%), while the freshwater aquaculture subsector was recording 1826 tons (DAFF 2015a; Britz and Venter 2016; DAFF 2017a) (Table 6). Aquaculture production grew by 4% (209 tons) compared to 2014 (DAFF 2017a). Mussel farming recorded the most significant production in 2015, followed by abalone and trout production while the marine finfish, Tilapia, catfish, oyster and marron are still in the new phase (DAFF 2017a). The mariculture industry in 2015 only consisted of 37 operational farms as compared to 152 operational freshwater farms. It, however, recorded about 66% of production volume and accounted for more than 80% of production value, mainly due to the contribution of the well-established high-value abalone subsector (Britz and Venter 2016; DAFF 2017a).

Aquaculture species in South Africa

The mariculture species farmed in South Africa include abalone (*Haliotis midae*), Pacific oyster (*Crassostrea gigas*), mussels (*Mytilus galloprovincialis* and *Chromomytilus meridionalis*), dusky kob (*Argyrosomus japonicus*) and seaweed (*Ulva* spp. L. 1758 and *Gracilaria* spp. Greville 1830) (DAFF 2015a). Freshwater aquaculture species include trout (*Oncorhynchus mykiss* and *Salmo trutta*), Tilapia

Table 7. Marine and freshwater aquaculture species and scale of operations in South Africa (DAFF 2015a, 2017a).

Marine aquaculture species			Freshwater aquaculture species		
Common name	Scientific name	Operational scale	Common name	Scientific name	Operational scale
Abalone	*Haliotis midae*	Commercial	Rainbow trout	*Oncorhynchus mykiss*	Commercial
Pacific oyster	*Crassostrea gigas*	Commercial	Brown trout	*Salmo trutta*	Commercial
Mediterranean mussel	*Mytilus galloprovincialis*	Commercial	Mozambique tilapia	*Oreochromis mossambicus*	Commercial
Black mussel	*Choromytilus meridionalis*	Commercial	Nile Tilapia	*Oreochromis niloticus*	Commercial
Seaweed	*Ulva spp*	Commercial	African Sharptooth catfish	*Clarias gariepinus*	Pilot
Seaweed	*Gracilaria spp*	Commercial	Common carp	*Cyprinus carpio*	Commercial
Dusky kob	*Argyrosomus japonicus*	Commercial	Koi carp	*Cyprinus carpio*	Commercial
Yellowtail	*Seriola lalandi*	Research	Marron (Freshwater crayfish)	*Cherax tenuimanus*	Commercial
White stumpnose	*Rhabdosargus globiceps*	Research			
Spotted grunter	*Pomadasys commersonnii*	Pilot			
Salmon	*Salmo salar*	Pilot			
Yellowbelly rockcod	*Epinephelus marginatus*	Research			
Mangrove snapper	*Lutjanus argentimaculatus*	Research			
South Coast Sea Urchin	*Tripneustes gratilla*	Research			
South African Scallop	*Pecten sulcicostatus*	Research			
Bloodworm	*Arenicola loveni*	Research			

(*Oreochromis mossambicus*, *Oreochromis niloticus* and *Oreochromis rendalli*), catfish (*Clarias gariepinus*), carp (*Cyprinus carpio*), marron crayfish (*Cherax tenuimanus*), as well as various ornamental species (DAFF 2015a).

The culture of marine finfish in South Africa is an emerging subsector with Dusky kob (*Argyrosomus japonicus*) as the only finfish being commercially grown. Ongoing studies, however, are currently being conducted on other species such as yellowtail (*Seriola lalandi*) for aquaculture potential while seaweeds are only grown for feeding abalone (Britz and Venter 2016) (Table 7). Trout (*Oncorhynchus mykiss* and *Salmo trutta*) farming is the most established freshwater aquaculture in South Africa and accounts for the largest aquaculture production in terms of volume, slightly surpassing abalone production, but abalone far exceeds trout in value. Increasing focus and efforts are being channeled toward growing the emergent Tilapia (*Oreochromis mossambicus*, *O. niloticus* and *Tilapia rendalli*), catfish (*Clarias gariepinus*) and marron crayfish (*Cherax tenuimanus*) freshwater aquaculture (Britz and Venter 2016). Ornamental species, mostly koi and common carp (*Cyprinus carpio*) are also cultured, but on a small-scale for the esthetic market.

Aquaculture production systems in South Africa

The South African aquaculture industry involves the culture of a wide variety of unrelated farmed aquatic species whose biology requires specific aquaculture practices (Figure 4), hence the need to describe aquaculture production systems for each species (FAO 2010-2020b).

Raceway systems

Raceway systems are intensive aquaculture systems primarily used for trout grow-out production, koi carp, carp and North African Sharptooth catfish (FAO 2010-2020b; DAFF 2015a).

Pond systems

Pond systems are used for semi-intensive to intensive grow-out production of trout, marron crayfish, dusky kob, catfish, Tilapia, koi carp, carp and ornamental fish (FAO 2010-2020b; DAFF 2015a).

Tank systems

Tanks are used mainly for the low-scale culture of ornamental fishes and carp, and primarily for the juvenile production of marron crayfish (FAO 2010-2020b; DAFF 2015a).

Cage systems

Cage culture systems have been successfully used for the grow-out production of trout and piloted on the offshore production of Salmon in South Africa (FAO 2010-2020b; DAFF 2015a).

Recirculating aquaculture systems

RAS is a reasonably advanced production technology compared to the regular production technology adopted by the other African countries, used mainly for the production of Tilapia (IDC 2015). The RASs are used predominantly in South Africa as efficient techniques of controlling water temperatures, quality and conserving water usage as the control of water

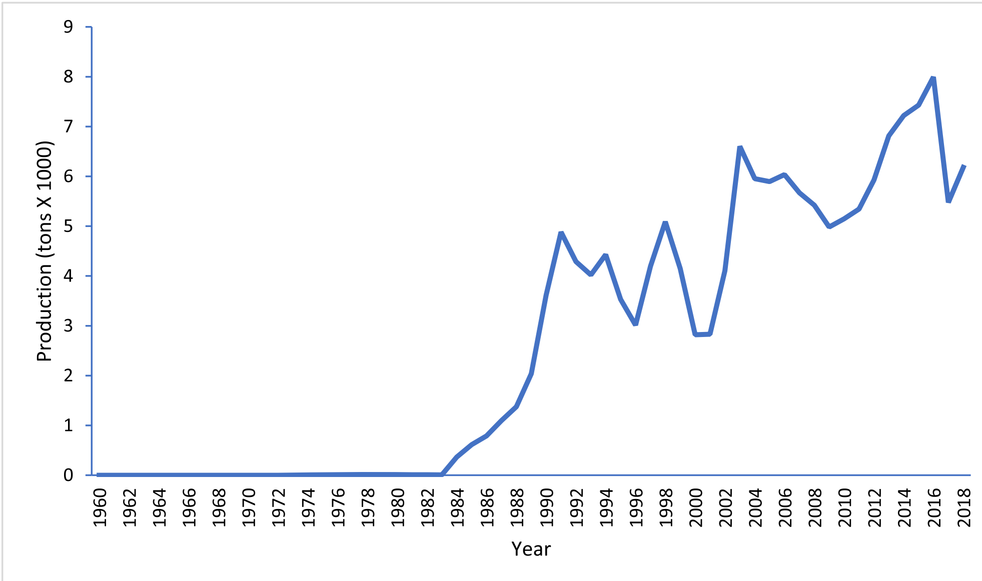

Figure 4. Aquaculture production in South Africa (1960–2018 in tons ×1000) (FAO 2010-2020b).

temperature is vital in Tilapia production in South Africa due to prevalent climatic conditions in most parts of the country (IDC 2015). Thermally regulated RASs have also been documented for the successful production of trout. Other aquaculture species cultured using RAS also include the North African catfish, koi carp, carp and ornamental species (FAO 2010-2020b; DAFF 2015a).

Integrated aquaculture systems: aquaponic systems

Aquaponics which is the synergetic production of fish and plants simultaneously in one circulatory system is an emerging and mainly practiced integrated aquaculture in the Republic of South Africa (Mchunu et al. 2017). South Africa largely adopted RAS technology, a fairly advanced technique, when compared to average technology currently being utilized in other African countries for the production of Tilapia. Aquaponics is a popular and well-established technology in developed countries; however, it is relatively new and rapidly developing in South Africa therefore, unlocking an innovative niche for sustainable food production (Mchunu et al. 2017).

Longline systems

Longlines systems are used in mariculture operation for the grow-out production of oysters and mussels (FAO 2010-2020b; DAFF 2015a).

Marine aquaculture

Abalone

Abalone is predominantly cultured in onshore land-based tank systems in South Africa. These land-based facilities are sited proximately to the coastline due to access to an unlimited quantity of seawater which is usually pumped ashore and pretreated in order to improve water quality (FAO 2010-2020b). Most land-based tanks are operated as FTSs where effluents are directly released into the environment, while in some farms, land-based tanks are operated as RAS and water are recycled through suitable filtration and treatment systems to improve growth and survival. Small scale cage culture of abalone is also practiced in the Western Cape, which involves stocking of juveniles in submersible cages that are suspended off the seabed (FAO 2010-2020b; DAFF 2015a). Abalone ranching is another production method which involves raising cultured hatchery juveniles within an allocated area in the wild until they attain the market size and harvest by the permit holder.

Oysters and mussels

Oysters are reared usually in submerged plastic mesh or nylon net cages suspended from longlines. Juvenile oysters are cultured on intertidal oyster racks before they are stocked out at sea off-bottom. Mussels are cultured using juveniles collected from a natural settlement on floating wooden raft or longlines with a series of suspended ropes (FAO 2010-2020b; DAFF 2015a).

Marine finfish

Intensive RASs are utilized in rearing Juveniles produced through induced spawning method and are subsequently moved to grow-out systems such as large land-based tank systems, flow-through saline earth ponds and offshore sea cages where juvenile fish are raised to market size. Offshore cage culture is still underdeveloped in South Africa, mainly due to high-energy shoreline and thus requires further considerations in technology (FAO 2010-2020b).

Ornamental marine species

Ornamental marine species in South Africa are cultured intensively in systems such as fish rearing tanks, coral propagation tanks, grow out tanks, quarantine tanks and display tanks (FAO 2010-2020b).

Mariculture in South Africa

South Africa has a vast coastline stretching 2798 km from the western desert border with Namibia on the Atlantic Ocean southwards around the tip of Africa and then northeast to the border with Mozambique on the Indian Ocean (FAO 2010-2020a). South Africa mariculture industry, although it is still evolving and quite low in production output, it is the most developed in Africa. It, however, significantly lags in production volume as compared to other nations with similar coastline length (FAO 2010-2020b).

South Africa recorded a total of 36 operational mariculture farms in 2013 (DAFF 2015a). The Western Cape Province recorded the highest number of operational mariculture farms in 2013. The province has 24 marine aquaculture farms operating in four sub-sectors, i.e. abalone, finfish, oysters and mussels; however, abalone represents the key contributor (DAFF 2015a). The Eastern Cape has six operational mariculture farms active in three sub-sectors which are abalone, oysters and finfish. The Northern Cape has five farms playing in the abalone and oysters sub-sectors, while KwaZulu-Natal has only one operational marine finfish farm (DAFF 2015a).

Challenges confronting the South African aquaculture industry

South Africa is endowed with good infrastructure, business institutions, and supply chains, however, the high energy coastline coupled with a water-scarce inland area limit the potential of aquaculture production (Britz and Venter 2016). Prevailing sub-optimal environmental conditions such as wide temperature variation, aridity combined with macroeconomic factors such as dearth of skilled human resources, fish prices, poorly developed value chain and complicated authorization procedures are mostly responsible for the challenges hindering the growth of aquaculture in South Africa (FAO 2010-2020b; Britz and Venter 2016).

Major difficulties experienced by potential investors include restricted access to suitable land and water. These difficulties include the rezoning process, onerous permitting requirements, and an obstructive bureaucracy in respect of compliance with environmental regulations (FAO 2010-2020b; Britz and Venter 2016). In terms of aquaculture technology, South Africa does possess a generally conducive infrastructure and supporting institutional environment for the development of large-scale commercial aquaculture (Britz and Venter 2016). There is, however, a lack of sector-level institutional coordination and strategy and certain specific infrastructure and capacity requirements that individual firms cannot overcome (DAFF 2015b). Before the release of the National Aquaculture Strategic Framework (NASF) and the National Aquaculture Policy Framework (NAPF) in 2012 and 2013 respectively, there has been a lack of a comprehensive set of national strategies and critical action plans for aquaculture (FAO 2010-2020b; Britz and Venter 2016).

Environmental condition

South Africa has a limited conducive environment for the development of aquaculture due to strong ocean currents and heavy wave actions, as well as a shoreline having limited sheltered bays of adequate size thus limiting the potential for commercial-scale mariculture of sea-cage farming (Britz and Venter 2016). South Africa, therefore, has successfully developed shore-based mariculture technology for the production of abalone (*Haliotis midae*) and dusky kob (*Argyrosomus japonicas*) however, production costs of pump-ashore are high, thus rendering shore-based mariculture technology suitable for only high-value aquaculture species (Britz and Venter 2016).

Also, scarcity of fresh inland water coupled with vast temperature variations between summer highs and winter lows make most parts of the nation unsuitable for the production of either cold or warm water aquaculture species in open systems (Britz and Venter 2016).

Land and water availability

There is the dearth of suitable area inland, lakes, rivers, estuaries in addition to access to suitable water supply in South Africa due to competitive use of these sites for recreational, agricultural and residential activities thus, a major hindrance to the development of aquaculture (Mahieu 2015). Also, accessing suitable land and water for aquaculture development is constrained by complications encountered by prospective investors which include but is not limited to rezoning process, arduous permit process and environmental regulations compliance (IDC 2015).

Complicated regulation

The over-regulation of the aquaculture sector, when compared to other food production sectors, is one of the major anti-enabling environments constraining the growth of aquaculture in South Africa (DAFF 2013). As a result of fragmented policies from different tiers of government departments, a prospective aquaculture venture will require at least thirteen different permits/licenses from different government departments to operate, which are issued in a cascading order thus needlessly prolonging the period of permit issuance (CSIR 2017). The complicated and ambiguous regulatory environment, therefore, makes it difficult for potential aquaculture venture to attract investment.

Other macroeconomic challenges

Other challenges that have stagnated the growth of aquaculture sector in South Africa include, but is not limited to, focus on a few but high-value species, scarce skilled resource persons and support services, the dearth of funds due to the reluctance of financial institution to fund aquaculture projects, high operating cost and weak marketing services (DAFF 2013; CSIR 2017).

Aquaculture marketing and trade

South African aquaculture products are sold both locally and internationally, depending on the species involved. The local aquaculture market is influenced typically by market price, species, consumer awareness and ease of accessibility. South Africa is not a traditional fish-eating country; however, the growing awareness of environmental sustainability and health concerns of consumers have led to the burgeoning demand for aquaculture products (DAFF 2017a). The abalone industry with high-value species exports bulk of their product for sale in Asia due to higher returns while most of the trout produced are sold locally (DAFF 2017b). South Africa exported almost 1399 tons of aquaculture products valued at R487.80 million in 2015, with Hong Kong representing the leading aquaculture products importer, followed by Botswana and Taiwan (DAFF 2017a).

Approximately 325 tons of Tilapia valued R3,5 million were exported from South Africa in 2015 with Botswana (196 tons), Democratic Republic of Congo (79 tons) and China (22 tons) being the three top destinations. The tilapia export market was growing and increased significantly by 323% with ten destinations recorded in 2014, and 3 more destinations added in 2015 (DAFF 2017a).

The primary processors developed the marketing system for aquaculture products in South Africa. These companies developed their cold storage facilities and supply network primarily to support their main aquaculture operations while there are also fully integrated marketing and merchandizing firms that handle distribution to the retail sector (DAFF 2017a).

South African aquaculture policies and framework

The Department of Environment, Forestry and Fisheries (DEFF) formerly known as the Department of Agriculture, Forestry and Fisheries (DAFF) is the lead national agency tasked with the responsibility for aquaculture sector development in South Africa. The National Aquaculture Strategic Framework (NASF) was developed in 2012 as a road map for the sustainable development of the aquaculture industry taken into consideration the current position of South Africa vis-à-vis global aquaculture production, challenges with creating enabling environment for aquaculture development, national food security as well as wealth and job creation (DAFF 2013).

The current NASF policy of DEFF aims to achieve the following objectives:

I. Encourage responsible and sustainable aquaculture development that is globally competitive.
II. Facilitate and support the optimal growth of the aquaculture industry in order to foster economic growth, food security and wealth creation.
III. Encourage private sector participation through the provision of required support services.

IV. Investment in research and development to aid industry growth, diversification and sustainable production.
V. Promote sustainable aquaculture development from a macroeconomic perspective.
VI. Promote adaptive aquaculture management that can promote innovations, data collection and knowledge transfer.
VII. Promote good governance for the full development of the aquaculture industry under a supportive regulatory framework.

The aquaculture policy intends to support both commercial and small-scale emerging farmers and to adopt a value-chain approach for the development of the aquaculture sector.

Qualitative SWOT analysis of Egypt, Nigeria, Uganda and South Africa

The internal and external SWOT analysis of the aquaculture sector of Egypt, Nigeria, Uganda and South Africa are summarized in Table 8. The key strengths of the Egyptian aquaculture sector are high production output and diversity of aquaculture species being produced (Table 8). The main weaknesses are due to overstretched water and land resources, as well as the prevalence of inefficient production systems (Table 8). High per capita fish consumption and prioritization of the aquaculture sector by the Egyptian government are the major opportunities; the sector is, however, currently being confronted by the threats of environmental and climate change impact; and lack of significant export of aquaculture products (Soliman 2017).

Availability of suitable land and water resources, coupled with the emergence of intensive urban and peri-urban aquaculture clusters are the major strength driving the growth of aquaculture in Nigeria (Obwanga et al. 2018). Soaring cost of feed, near absence of mariculture and focus on *Clarias* spp. are the major weaknesses of the Nigerian aquaculture sector (Obwanga et al. 2018). Huge and widening demand-supply gap of fish, as well as the gradual ban of fish importation, are the key opportunities that can be leveraged by the aquaculture sector, unstable policies and poorly implemented framework are however major threats hindering the development of the sector (Table 8).

The key strengths of the aquaculture sector of Ugandan are the availability of suitable land and vast networks of inland water resources (Table 8). Growing adoption of cage culture is also contributing to the development of the sector (Table 8). Similar to Nigeria, the aquaculture sector of Uganda is focused mainly on Tilapia and catfish; the sector is also plagued by the shortage of local commercial-scale aquafeed production (Rutaisire et al. 2017). Uganda is a major supplier of fish to her neighboring countries and potentially positioned as key fish processing hub in the East African region (Cai et al. 2017). The sector is, however, threatened by a weak enabling environment (Mwanja 2007).

The major strength of South Africa is its diversified environment, suitable for the production of both warm and cold-water aquaculture species (CSIR 2017). The sector also boasts efficient production technology but focus on high-value species with low production output, and overstretched inland water resources are major weaknesses of the South African aquaculture sector (Table 8). Major opportunities in this sector are growing institutional support primarily driven by the government and established export markets (Table 8). Very low per capita consumption of fish (7.5 kg) compared to the global average of 17 kg and complicated authorization processes are the major threats confronting the growth of the sector (Table 8).

Critical success factors of key players (Egypt, Nigeria and Uganda) vis-à-vis South Africa

Market demand

The domestic demands for fish driven by high per capita consumption of fish amongst the key players have been driving the growth of aquaculture production (Kawarazuka 2010; Soliman and Yacout 2016; Atanda and Fagbenro 2017). The market for fish in Egypt is characterized by simple but efficient value chain and market systems; thus, fish is easily accessible in the markets within a short time (Table 8). Nigeria has a well-developed value chain for catfish (Obwanga et al. 2018). A key emerging trend is the growth of peri-urban aquaculture and the establishment of Fish Farming Estates (FFEs) in large urban areas thus enabling access to large markets and reduction in post-harvest losses due to infrastructure challenges (Cocker 2014; Obwanga et al. 2018). Production in Uganda is dominated by Tilapia and catfish aquaculture (Cocker 2014). Catfish in Uganda is considered as a niche product in the market and commands higher prices than Tilapia due short supply of both wild and farmed catfish (Cocker 2014). The key players can leverage the opportunity of growing export markets regionally and globally through standardization of aquaculture products. South Africa in

Table 8. SWOT analysis of Egypt, Nigeria, Uganda and South Africa (FAO 2004-2020; Fagbenro and Adebayo 2005; El-Sayed 2007; FAO 2007-2020b; Nassr-Alla 2008; FAO 2010-2020b, 2011; Jamu et al. 2012; El-Sayed 2013; Oyakhilomen and Zibah 2013; Nasr-Allah et al. 2014; Ozigbo et al. 2014; Adewumi 2015; El-Sayed et al. 2015; Britz and Venter 2016; Soliman and Yacout 2016; DAFF 2017; Rutaisire et al. 2017).

Internal factors		External factors	
Strengths	Weaknesses	Opportunities	Threats
I. High production output and value –highest in Africa II. Culture of diverse aquaculture species III. Produces freshwater and marine species IV. Aquafeed manufacturing capacity V. Functional government hatcheries VI. Research and development capacity VII. Vast coastline for mariculture VIII. Major employer of Labor	I. Overstretched and limited water resources II. Dearth of suitable aquaculture sites III. Inefficient production systems IV. Lack of processing capacity V. Production limited by seasonality VI. Dependence on imported fish feed ingredients; VII. Poor infrastructure	I. High per capita consumption of fish II. Burgeoning local demand III. Favorable location for mariculture IV. Strong institutional support from government V. Development of desert aquaculture	I. Lack of significant export due to poor product standard II. Climate change and environmental impact III. Price fluctuation IV. Preference for wild captured fish by consumer V. Poor currency performance
I. High product value and growing capacity II. Intensive urban and peri-urban production systems III. Feed production capacity IV. Availability of fish seed due to many privately-run hatcheries V. Research and development capacity VI. Well established Catfish value chain VII. Some levels of processing and packaging capacity VIII. Availability of suitable land and inland water IX. Large employer of labor X. Establishment of fish farming estates/clusters in urban/peri-urban areas	I. Highly focused on a single species II. High cost of feed III. Near absence of mariculture IV. Preference for live fish V. Underutilized potential aquaculture land VI. Importation of brood stocks VII. Poor storage and processing facilities VIII. Reliance on imported and expensive feed IX. High cost of inputs X. Poor access to credit facilities XI. Shortage of extension workers and services	I. High per capita consumption of fish II. Huge demand-supply gap III. Growing export market IV. Policy shift toward commercial aquaculture V. Government imposed fish importation quotas to protect sector.	I. Illegal fish trade with neighbors II. Poor implementation of legal framework; III. Unstable policies by successive governments IV. Growing tilapia production for export
I. Availability of suitable land and inland water resources II. Lower cost of feed production III. Advent and growth of cage culture IV. Availability of fish seed due to many privately-run hatcheries V. Existence of artisanal and commercial scale processing	I. Largely focused on tilapia and catfish species II. Most fish culture is done in earthen ponds III. Limited commercial scale feed production IV. Skill shortage V. Uganda is land locked therefore, absence of mariculture VI. Most fish are sold fresh and unprocessed. VII. Poor storage and processing facilities	I. Huge demand-supply gap II. Growing regional market demand III. Potential for processing and export	I. Poor record of regional export II. weak institutional capacity, poor governance and political instability III. Obsolete policies and framework
I. Culture of diverse aquaculture species II. Efficient production technology III. Produces freshwater and marine species IV. Commercial scale aquafeed manufacturing capacity V. Vast coastline for mariculture VI. Research and development capacity VII. Food processing capacity VIII. Established aquaculture producer associations	I. Unprotected open coastal sites exposed to high wave energy II. Focused on high value species with low production output III. Limited research into various segments of aquaculture IV. Lack of extension services V. Limited and overstretched freshwater resources VI. Absence of functional government hatcheries VII. Limited suitable land VIII. Reluctance of financial institutions to fund aquaculture projects	I. Growing demand for affordable protein and shortage in traditional fish products II. Potential for export III. Aquaculture receiving government attention and support IV. Connection with tourism V. Conducive economic climate for aquaculture industry VI. Enabling policies and framework	I. Lack of marketing services, structures and penetration II. Very low par capital consumption of fish III. Complicated Permits and registration procedures. IV. Shortage of expertise and aquaculture professionals V. Dearth of aquaculture veterinary services and disease management VI. Impact of climate change

contrast, is typically not a fish-eating country as demonstrated by its low per capita (7.5 kg per person) compared to the global average of 17 kg per person (Britz and Venter 2016). South African aquaculture is characterized by meager and insignificant production output due to the myriads of challenges (Britz and Venter 2016; DAFF 2017a).

Infrastructure

The availability and accessibility to essential infrastructure are highly valuable to the development of aquaculture amongst the key producers (Cai et al. 2017). The presence of many feed mills with high production capacity and proximity to the fish farm is a common success factor among the key players (Table 8). In addition to high feed milling capacity in Egypt, both the government and private sectors are actively involved in establishment and operations of hatcheries, as well as research, training and dissemination facilities (Cai et al. 2017). As a result of the success recorded with the establishments of fish farm estates in Nigeria, the government became persuaded and involved with infrastructure improvement and provision to boost aquaculture production output (Ozigbo et al. 2014; Atanda and Fagbenro 2017). Aside from many privately-operated hatcheries which are responsible for the availability of fingerlings, the Ugandan government is developing aquaculture parks (a fish farm cluster with shared amenities) countrywide to lower cost and boost production output (Cocker 2014). South Africa, on the hand, has infrastructure capability to support high feed and fish seed production output; however, there are only a few firms which are sited far away from many fish farms. The support from government is focused mainly on creating an enabling environment for aquaculture production through policies (DAFF 2013).

Environment

Land and water availability, as well as favorable climatic conditions, are relevant factors for aquaculture development (Cocker 2014). Egypt experiences warm temperatures for the most of the year, which is conducive for warm water fish aquaculture, however, due to the prevailing desert climate, it is limited by the availability of suitable land and water (Cai et al. 2017; Soliman 2017). Nigeria and Uganda are both endowed with arable land and water, as well as enjoy warm tropical climate suitable for aquaculture production (Ozigbo et al. 2014; Adewumi 2015; Rutaisire et al. 2017). South Africa has a water-scarce inland area, highly exposed shoreline and sub-optimal climate; thus, limited by the availability of suitable natural environment for conventional aquaculture production (FAO 2010-2020b; Britz and Venter 2016).

Technology

Adoption of improved technology has been identified as a key success factor and mitigant against environmental factors limiting the development of aquaculture (Soliman 2017). Besides adopting efficient fish production systems, the key producers are also embracing cutting-edge technology in feed production, hatchery operations and fish processing (El-Sayed et al. 2015; Soliman and Yacout 2016; Atanda and Fagbenro 2017; Rutaisire et al. 2017). A paradigm shift in production technology to the adoption of efficient water systems such as desert aquaculture, intensive earthen pond production and development of integrated aquaculture systems immensely contributed to the rapid expansion of aquaculture production in Egypt (Soliman 2017).

Commercialization

Aquaculture development activities are concentrated often on production techniques at the expense of its business development, aquaculture will not be, however, sustainable, if not managed and promoted as a business (Muir 2005; Cocker 2014). The aquaculture sector in Egypt has attracted both private and government sector investments, notably in the feed and fish seed production segment of the value chain (Table 8). The fish farm estate (FFE) models contribute more than 80% of aquaculture production in Nigeria and mostly responsible for the development of the Nigerian aquaculture industry value chain (Obwanga et al. 2018). This FFE model is predominantly driven by the private sector and attracting both local and foreign investments in the aquaculture industry (Ozigbo et al. 2014; Atanda and Fagbenro 2017). Most of the aquaculture development initiatives in Uganda with regards to production and processing is driven primarily by private sector investment (Dickson et al. 2012). The aquaculture sector of South Africa is mainly private sector driven due to aquaculture development policy shift from a production to a value chain driven development strategy (DAFF 2013; Britz and Venter 2016).

Institutional support and skill development

Institutional support is rendered by the government through the development of policies to create an enabling environment for aquaculture development (Cocker 2014; Obwanga et al. 2018). All the four countries appeared to have aligned their policies in line with the NEPAD 2005 summit priority actions geared toward aquaculture value chain development and commercialization. As a result of this policy shift, the aquaculture sector of these countries began to witness the private sector and foreign investments and growth (Cocker 2014). The role of capacity building across the aquaculture value chain is undertaken by research institutions, vocational centers and universities. Nigeria and Egypt have many well-established aquaculture research institutions and universities undertaking research, training and technology transfer (Obwanga et al. 2018)

Conclusion

Aquaculture was initially introduced to Africa by colonizers as recreational fishing activities and later evolved into a means of attaining food security and livelihood from the 1940s. The successful development of pond aquaculture across the region spurred the donor agencies to fund research and development activities on the cultural methods of mostly indigenous fish species. Aquaculture development donor funding across Africa started experiencing a decline from the early 1990s due to the change of priority to other pressing sectors such as health, education and governance. As a result of paucity of funds from donor agencies, aquaculture development across the region stagnated, and production output experienced a decline.

Interest and growth of aquaculture across the region were revived through global awareness raised by NEPAD fish for all summit of 2005 and the SPADA interventions coordinated by FAO. As a result, aquaculture production output experienced a twenty-fold increase in the past 25 years, primarily driven by commercial-scale investment in Egypt, Nigeria, Uganda and Ghana. Aquaculture development in Africa is being sustained by many governments creating an aquaculture development centered conducive business environments through policy reforms and frameworks as a roadmap. Provision of enabling environments resulted in the burgeoning private sector-controlled aquaculture value chain development, notably in Nigeria, Egypt, Uganda and Ghana.

Almost all the aquaculture production from the region comes from inland freshwater systems mainly focused on native catfish and tilapia species cultured in tanks, ponds, cages and improved production systems such as RAS and aquaponics.

Key challenges plaguing the pace of aquaculture development are access to credit facilities, adequate supply of required quantity and quality of inputs, land ownership and product marketing. The distribution of aquaculture products is exacerbated further by dilapidated and inadequate infrastructure and facilities.

The critical success factors driving aquaculture development and production output of the key players were high per capita consumption of fish, optimal environment, infrastructure, technology, commercialization, provision of an enabling environment and skill development.

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