FAS Fisheries and Aquatic Sciences

Original Article
Fish Aquat Sci 17(1), 1-11, 2014

An Overview of Kenyan Aquaculture: Current Status, Challenges, and Opportunities for Future Development

Jonathan Mbonge Munguti[1]*, Jeong-Dae Kim[2] and Erick Ochieng Ogello[3]

[1]Kenya Marine & Fisheries Research Institute (KMFRI), National Aquaculture Research Development & Training Center (NARDTC) Sagana, P.O. Box 26, Sagana, Kenya
[2]Department of Animal Life System, College of Animal Life Sciences, Kangwon National University, Chuncheon 200-701, Korea
[3]Kenya Marine and Fisheries Research Institute (KMFRI), Kegati Aquaculture Research Station, P.O. Box 3259, Kisii, Kenya

Abstract

The Kenyan aquaculture sector is broadly categorized into freshwater aquaculture and mariculture. Whereas freshwater aquaculture has recorded significant progress over the last decade, the mariculture sector has yet to be fully exploited. The Kenyan aquaculture industry has seen slow growth for decades until recently, when the government-funded Economic Stimulus Program increased fish farming nationwide. Thus far, the program has facilitated the alleviation of poverty, spurred regional development, and led to increased commercial thinking among Kenyan fish farmers. Indeed, national aquaculture production grew from 1,000 MT/y in 2000 (equivalent to 1% of national fish production) to 12,000 MT/y, representing 7% of the national harvest, in 2010. The production is projected to hit 20,000 MT/y, representing 10% of total production and valued at USD 22.5 million over the next 5 years. The dominant aquaculture systems in Kenya include earthen and lined ponds, dams, and tanks distributed across the country. The most commonly farmed fish species are Nile tilapia *Oreochromis niloticus*, which accounts for about 75% of production, followed by African catfish *Clarias gariepinus*, which contributes about 21% of aquaculture production. Other species include common carp *Cyprinus carpio,* rainbow trout *Oncorhynchus mykiss,* koi carp *Cyprinus carpio carpio*, and goldfish *Carassius auratus*. Recently, Kenyan researchers have begun culturing native fish species such as *Labeo victorianus* and *Labeo cylindricus* at the National Aquaculture Research Development and Training Centre in Sagana. Apart from limited knowledge of modern aquaculture technology, the Kenyan aquaculture sector still suffers from an inadequate supply of certified quality seed fish and feed, incomprehensive aquaculture policy, and low funding for research. Glaring opportunities in the Kenyan aquaculture industry include the production of live fish food, *e.g.*, *Artemia*, daphnia and rotifers, marine fish and shellfish larviculture; seaweed farming; cage culture; integrated fish farming; culture of indigenous fish species; and investment in the fish feed industry.

Key words: Aquaculture, Kenya, Challenges, Opportunities, ESP, KMFRI

Introduction

Growth of the global aquaculture industry has been sporadic over the last 50 years, and the global production capabilities of culture and capture fisheries are almost comparable (Food and Agriculture Organization of the United Nations, 2012). The sporadic growth has been largely attributable to technological advancements in fish production, *e.g.*, hybridization, genetic engineering, formulated diets, and biofloc technology used in ponds, cages, tanks, and recirculation systems (Food and Agriculture Organization of the United Nations, 2012). However, the rate of growth of global aquaculture has differed across

http://dx.doi.org/10.5657/FAS.2014.0001

Received 14 August 2013; **Revised** 7 January 2014
Accepted 9 January 2014

***Corresponding Author**
E-mail: jonathanmunguti@hotmail.com

http://e-fas.org pISSN: 2234-1749 eISSN: 2234-1757

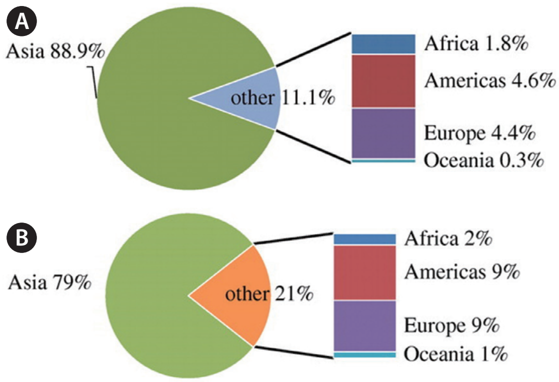

Fig. 1. Global aquaculture productions by region, (A) Aquaculture by quantity 2008 (excluding aquatic plants). (B) Aquaculture by value 2008 (excluding aquatic plants) (source: Food and Agriculture Organization of the United Nations, 2010).

continents. Whereas continental Asia has become the giant in aquaculture production, Africa has yet to report any significant quantities of aquaculture on the global scale despite the availability of enormous natural resources in some regions (Food and Agriculture Organization of the United Nations, 2010). Africa contributes only 1.8% of global aquaculture production (Fig. 1) (El-Sayed, 2006; Bostock et al., 2010; Food and Agriculture Organization of the United Nations, 2010), although African aquaculture is currently undergoing an exciting phase of growth after numerous false starts, perhaps as a reaction to the high incidence of poverty, malnutrition, and unemployment (Hecht, 2000). Africa has great potential for fish farming with 37% of its surface area suitable for artisanal fish farming and 43% for commercial fish production (Aguilar-Manjarrez and Nath, 1998).

Fish farming was first begun in Kenya by colonists in the early 1900s through introduction of trout in rivers for sport fishing (Ngugi et al., 2007). This progressed into static pond culture of species such as tilapia, common carp, and catfish in the 1920s (Maar et al., 1966). Indeed, the establishment of Sagana and Kiganjo fish farms for production of warm- and cold-water seed fish in 1948 was the beginning of small-scale rural fish farming in Kenya, which became popular in the 1960s (Ngugi and Manyala, 2004; Nyonje et al., 2011). Furthermore, "eat more fish campaigns" promoted by the government in the late 1960s also accelerated the interest in rural fish farming (Ngugi and Manyala, 2004; Ngugi et al., 2007). The primary cultured fish species in Kenya today are Nile tilapia (75%) and African catfish (15%) (Ngugi and Manyala, 2004), but efforts to introduce other indigenous fish, such as *Labeo victorianus,* in aquaculture have not been widely adopted by farmers. Mariculture was introduced in the late 1970s with the establishment of the Ngomeni Prawn Pilot Project (Nyonje *et al*., 2011). Unfortunately, the marine water fisheries remain underexploited, mainly due to accessibility problems, conflicts over land ownership, and lack of clear policies. Despite the enormous potential for fish farming in Kenya, aquaculture has been characterized by low levels of production that have stagnated at less than 1% of the country's protein needs over the past decade (Nyonje et al., 2011). This is due to many challenges, which will be addressed later in this paper. With population growth escalating to unsustainable levels and increasing food insecurity, Kenya's dwindling capture fisheries are unable to adequately provide cheap protein for the growing population. Natural water bodies, which have also been instrumental in fish production, have had their share of challenges, ranging from pollution to reduction of water levels that compromise fisheries (Lake Victoria Basin Commision, 2011; Obiero et al., 2012). In light of these problems, aquaculture is the best opportunity to bridge the escalating gap of supply and demand for fish. For aquaculture to register substantial growth and meet its potential, development of Kenyan aquaculture must be refocused. This paper explores the current status, challenges, potentials, and future opportunities for the Kenyan aquaculture sector. We focus on the potential of current aquaculture production systems and reveal opportunities for improvement. The current aquaculture species and inputs (feed and seed fish) in the Kenyan aquaculture sector are also discussed.

Current Status of Kenyan Aquaculture

Kenya is endowed with several inland natural water resources such as Lakes Victoria, Turkana, Baringo, Naivasha, Chala, Kanyaboli, and Jipe, among others. Major rivers include the Tana, Athi, Nyando, Nzoia, Gucha, Migori, Yala, and Mara. In addition to artificial water bodies from dams, which are spread across the landscape, Kenya boasts approximately 600 km of coastal shoreline with an Exclusive Economic Zone of 200 nautical miles, which could be harnessed to enhance aquaculture. Although most parts of the country are suitable for aquaculture, only about 0.014% of the 1.4 million ha of potential aquaculture sites are used for aquaculture and about 95% of fish farming is on a small scale (Otieno, 2011). In addition, fish farming has been practiced mostly in the central, Nyanza, western provinces, and parts of Rift Valley and coastal provinces (Nyonje et al., 2011).

Since the beginning of Kenyan aquaculture in the 1950s until 2006, total annual aquaculture production has never exceeded 2,000 MT/y (Fig. 2). Prior to the government-funded Economic Stimulus Program (ESP), about 7,500 fish farmers, mostly from the Rift Valley and central provinces, held about 7,477 production units in an estimated area of 722.4 ha (Nyonje et al., 2011). By 2007, the mean yield from fish farming was approximately 5.84 MT yr^{-1}, compared to 4,452 MT of the total annual fish production, and was valued at $10.78 million, accounting for only 3% of the total fish production (National Economic Survey, 2006). Recognizing aquaculture as one of the viable options for revamping the country's food sector, the

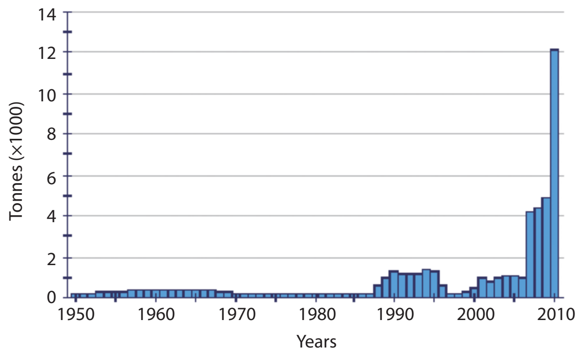

Fig. 2. Reported aquaculture production in Kenya (from 1950 to 2010) (source: Food and Agriculture Organization of the United Nations, 2010).

Kenyan government initiated the ambitious ESP in 2009 to stimulate economic development, foster economic recovery, alleviate poverty, and spur regional development (Nyonje et al., 2011). The Fish Farming Enterprise Productivity Program under the ESP was aimed at injecting commercial thinking into fish farming to build up a vibrant aquaculture industry. The program aimed to increase production of farmed fish from 4,000 MT to over 20,000 MT in the medium term and to more than 100,000 MT in the long term (Charo-Karisa and Gichuri, 2010). In the first year of the program, 200 fish ponds were constructed in each of 140 constituencies, totaling more than 27,000 fish ponds nationally (Charo-Karisa and Gichuri, 2010; Musa et al., 2012). This triggered an immediate short-term demand for about 28 million certified tilapia and catfish fingerlings and over 14,000 MT of formulated fish feeds, which could not be adequately and timely supplied, even by the private sector (Musa et al., 2012). The ripple effect of the ESP led some farmers to dig their own ponds, further increasing the demand for seed fish and feed to over 100 million and 100,000 MT, respectively (Charo-Karisa and Gichuri, 2010; Musa et al., 2012). Apart from the effects of the ESP, most people who abandoned subsistence farming for fish farming, and new farmers practicing commercial aquaculture, now own bigger ponds, resulting in higher yields (Otieno, 2011). Indeed, current national aquaculture production, including harvests from the ESP and other private farms, is estimated at 12,000 MT/y (Fig. 2), equivalent to 7% of the total production and valued at $21 million (Nyonje et al., 2011). Production is projected to hit 20,000 MT/y, representing 10% of national fish production, in the next 5 years (Nyonje et al., 2011). This presents a lucrative opportunity for aquaculture development in the feed and seed fish sectors, which unfortunately still suffer from basic problems.

To date, the Kenyan government has designated several aquaculture facilities in various parts of the country to serve as research centers, training facilities, and sources of fingerlings and feed for fish farmers. They include the National Aquaculture Research Development & Training Center (NARDTC) in Sagana, Kisii fish farm training center, Kiganjo trout farm, Ndaragua trout farm, Chwele fish farm, Lake Basin Development Authority (LBDA) in Kisumu, Wakhungu fish farm in Busia, Sangoro research station, Kegati research station, and Kabonyo and Ngomeni fish farms. However, most of these centers lack basic laboratory equipment and human capacities to spur significant aquaculture development in their respective spheres of influence.

Productivity of Aquaculture Systems in Kenya

Like in other African countries, fish farming in Kenya has been extensive but less intensive (Ngugi et al., 2007). Intensive fish farming is unpopular due to the high cost of infrastructure advancements and the knowledge needed. However, some farmers on the outskirts of major towns and cities are becoming more receptive up to recirculating aquaculture systems, technologies that can help tap into the lucrative fish market in cities. The motivation for this is due to high production capacities within a small area, since land around the cities is expensive. The fish farmer's decision of the optimal culture method is influenced largely by environmental, economic, and managerial challenges that pose problems for many fish farmers (De Graaf et al., 2005). Table 1 shows the current num-

Table 1. The Kenya national distribution of fish culture systems and the respective cover area (m^2) 2009

Province	No. of farmers	Ponds		Dams		Tanks		Total	
		No.	Area	No.	Area	No.	Area	No.	Area
Central	1,339	1,609	506,605	167	1,933,809	83	18,744	1,859	2,459,158
Coast	184	434	58,698	-	-	9	180	434	58,698
Eastern	538	752	423,628	20	113,018	3	118	775	536,764
Nyanza	1,360	2,070	453,423	15	41,220	1	27	2,086	494,670
R. Valley	1,242	1,531	761,856	129	3,385,298	65	4,015	1,725	4,151,169
Western	1,665	2,720	549,486	-	-	-	-	2,720	549,486
Total	6,328	9,116	2,753,696	331	5,473,346	161	23,085	9,608	8,250,127

Source: Otieno (2011).

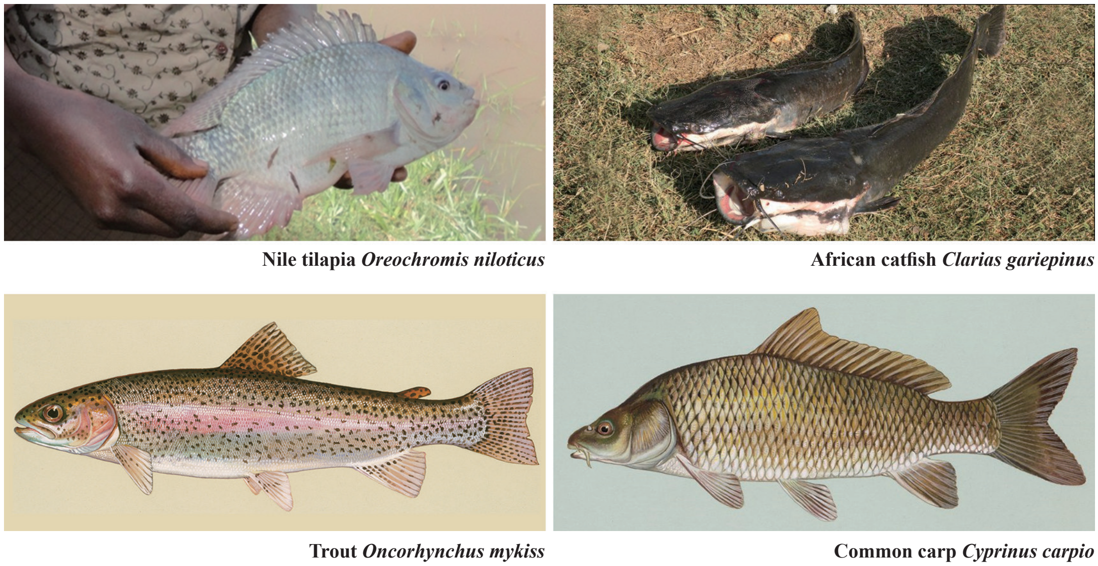

Fig. 3. The plate showing the commonly farmed freshwater fishes in Kenya.

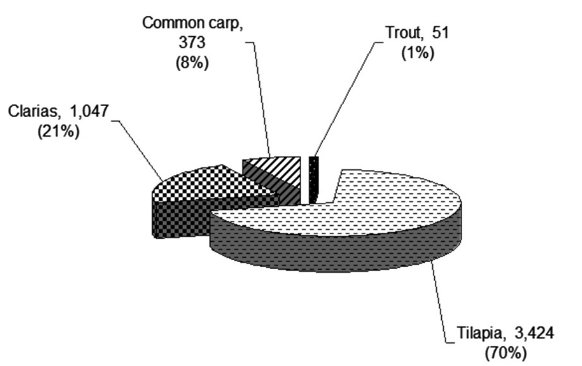

Fig. 4. Aquaculture production by species in 2009 (adapted from Otieno, 2011). Fish culture in the earthen and Liner ponds.

ber of fish culture systems in Kenya as a result of the effects of ESP and its ripple effects. The absence of data from other systems, such as cages, recirculating systems, and raceways, is a clear indication that the Kenyan aquaculture sector has room for expansion. Indeed, these are some of the areas that could be lucrative not only to local investors but also foreign investors.

As late as 2011, about 5,000 tons of various farmed fish species (Fig. 3) valued at $12.3 million were harvested (Otieno, 2011). As usual, tilapia *Oreochromis niloticus* contributed the bulk of the fish, yielding about 3,400 tons (69.9%), followed by African catfish *Clarias gariepinus* at 1,047 tons (21%), common carp *Cyprinus carpio* at 373 tons, and trout *Oncorhynchus mykiss* at 51 tons (Fig. 4). Other farmed fish that were harvested in small quantities included black bass, koi carp, and goldfish (Otieno, 2011). Recognizing that the production of currently farmed fish species in Kenya depends on the productivity of the farming systems used is important. As of now, pond culture is dominant.

Fish Culture in Earthen and Lined Ponds

Fish farming in earthen ponds has been advocated for the development of cheap food resources in developing nations (Food and Agriculture Organization of the United Nations, 2000). Over 90% of cultured fish in Sub-Saharan Africa come from earthen ponds of between 200 and 500 m^2 (Ngugi et al., 2007; Mucai et al., 2011), where fish are fed primarily with locally available low cost agricultural by-products. This method of fish culture is popular in Kenya due to the low cost of establishment and generally good soil in most places, *e.g.*, in the western province (Musa et al., 2012). In places where the soil is not suitable, farmers have been encouraged to buy Ultraviolet-treated liners to reduce water loss through seepage. However, this option is too expensive for the majority of farmers. In such areas, we suggest that recirculating aquaculture should be encouraged through government and private sector initiatives. Fish ponds in Kenya range from small dug holes to designed ponds with inlet and outlet channels (Fig. 5) and harvest basins yielding approximately 1-2 tons/ha/y under competent management (Brummett and Noble, 1995). Despite its commonality, pond culture has not been fully exploited and most production in rural yards is unreported. Tilapia ponds can be managed intensively or semi-intensively, depending on whether fertilizers and complete feeding are applied. Some fish farmers still embrace low productivity systems of culture, where ponds are naturally stocked by flooding from rivers and lakes (Denny et al., 2006).

Fig. 5. The plate showing liner and earthen ponds in Kenya. Picture by Jonathan Mbonge Munguti.

Fig. 6. The plate showing tilapia cages in Dunga beach, Lake Victoria, Kenya. Picture by Erick Ochieng Ogello.

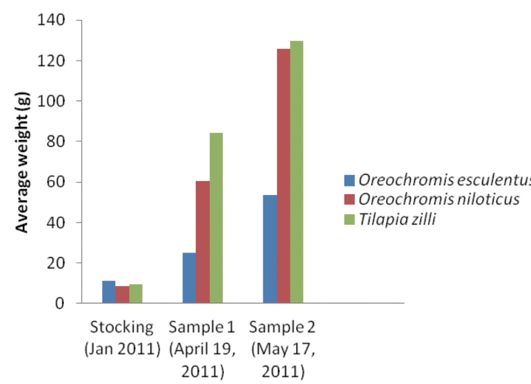

Fig. 7. Mean weight (g) of different tilapia species stocked in 8 m^3 cages at density of 100 fishes/m^3 in Lake Victoria, Kenya.

Tank Fish Farming

In cases of land and water scarcity but favorable economic conditions, tank farming is a good alternative to ponds or cages. Tests have shown that fish can be grown at high densities in the confinement of tanks under quality management (Rakocy, 1989). During the production cycle, high fry stocking density is reduced at regular intervals to minimize crowding and ensure good water quality. Tank fish farming in Kenya is limited. In fact, we could find no literature to confirm the existence of fish tank farming in Kenya, which could be due to operational limitations, but it provides an unexploited opportunity for investment.

Cage fish farming

Fish farming in cages is done in existing water bodies (ponds, rivers, lakes, dams, and oceans). The fish are enclosed in a cage that allows free water exchange. Only strong, durable, and nontoxic materials are used to construct the cages, which vary in size and shape. The location of the cage in the water body may be critical for proper water circulation. Although little information is available on cage culture in Kenya, it may be an overlooked asset in the aquaculture sector. As fish cage culture in Lake Victoria has begun relatively recently, productivity data are largely lacking. Over the last 3 years, the Kenya Marine and Fisheries Research Institute (KMFRI) initiated preliminary trials of tilapia cage culture off Dunga beach in Kisumu, where impressive growth of *Oreochromis niloticus, Oreochromis esculentus*, and *Tilapia zilli* were reported (Fig. 6). Different species of mixed sex tilapia from the selected breeding program in Sagana were cultured in 8-m^3 cages in Lake Victoria. Preliminary results showed that *O. niloticus* performed better than the native *O. esculentus,* gaining 175 g within 4 months compared to 150 g for *T. zilli* (Fig. 7). Further opportunities exist for development of cage culture in Kenya by using improved fish species such as genetically improved farmed tilapia (GIFT).

Fig. 8. The plate showing tilapia BOMOSA cages Ngeki dam in Machakos County, Kenya. Picture by Jonathan Mbonge Munguti.

Fig. 9. The plate showing integrated fish farming at Sangoro Kenya Marine & Fisheries Research Institute Picture by Jonathan Mbonge Munguti.

Fish farming in dams

The construction of dams was also encouraged under the ESP, not only to provide water but also to encourage communal fish farming activities. Fish farming in dams is not very popular in Kenya and thus not well documented. However, dams have been used to house cages for experimental and research activities, such as the recently completed regional BOMOSA (2009) project, a multidisciplinary research project funded by the European Union (Fig. 8). This is another area that has not been fully exploited in Kenyan aquaculture.

Integrated fish farming

An integrated fish culture approach involves the connection of agricultural systems to fish farming in a design that allows waste from one system to be used as input in another system, conserving resources and boosting returns (Edwards, 1980; Chen, 1989; Ayinla, 2003; Shoko et al., 2011). Through its biophysical and socioeconomic benefits, integrated fish farming has immense potential to address income instability, nutritional insecurity, unemployment, and poverty of farmers, not only in Kenya, but across East Africa (Ogello et al., 2013). Integrated fish farming is inexpensive and profitable and is another overlooked asset for present and future aquaculture development in the East African region (Ogello et al., 2013).

In Kenya, integrated fish culture is still in nascent stages of development with demonstrational infrastructure present in state-owned institutions such as the LBDA in Kisumu and the KMFRI in Sagana and Sangoro (Fig. 9). Nevertheless, farmers have embraced the practice across the country where they use mainly chicken and cow manure for pond fertilization, and have recorded impressive performance in some areas (Ogello and Opiyo, 2011; Ogello et al., 2013). Studies on integrated fish culture on the Kenyan side of the Lake Victoria Basin reported that a 200 m^2 fish pond of *O. niloticus* fertilized with cow manure provided an additional per capita fish supply of 3.4 kg to a household of seven people for an average annual productivity of about 200 kg/ha/y (Denny et al., 2006). However, this is a low-intensity system in which no feed is supplied. In the recently funded fish farming ESP project, no funds were allocated to the integrated fish farming despite its enormous potential.

Current Status of the Kenyan Fish Feed Industry

Fish feed is a key component in any fish-farming venture because fish nutrition accounts for 40-50% of the total variable production costs on the fish farm (Craig and Helfrich, 2002; Munguti and Charo-Karisa, 2011). One of the most pressing current challenges in Kenyan aquaculture is the lack of efficient and inexpensive farm-made feeds for different stages of fish development (Munguti et al., 2012). In reaction to the ESP project, the Kenyan fish feed sector experienced a shortage of

14,000 MT/y (Charo-Karisa and Gichuri, 2010). Since then, demand has increased tremendously to about 50,000 MT/y. Due to the increased demand for fish feed, unscrupulous dealers sometimes sell feed of compromised quality, prompting the government to initiate efforts to establish national standards for fish feed. The fish feed standards (Table 2) were a culmination of several meetings and negotiations between all aquaculture stakeholders: the KMFRI, the Ministry of Fisheries, commercial feed companies, fish farmers, and the Kenya Bureau of Standards (KBS).

Most fish farmers in Kenya add manure or inorganic fertilizer to ponds because it increases the supply of natural food

Table 2. The Kenyan commercial fish feed standards for catfish and tilapia fry, fingerlings, growers and brooders

Feed parameters	Fry	Fingerlings	Growers	Brooders
Feeding rate	5% b.w	6-8% b.w	3% b.w	3% b.w
Crude protein (%)	40-45%	35-40%	30-34%	40%
Energy (MJ/kg)	≥ 10	≥ 10.5-11	≥ 11.5-12.5	
Crude fiber CF (%)	≥ 4	≥ 4	≥ 6	≥ 6
Lipids (%)	≥ 8	≥ 8	≥ 10	≥ 10
Lysine (%)	≥ 12	≥ 12	≥ 12	≥ 12
Methionine (%)	≥ 5	≥ 5	≥ 5	≥ 5
Shelf life (mo)	≥ 6	≥ 6	≥ 6	≥ 6
Moisture content (%)	≤ 12	≤ 12	≤ 12	≤ 12
Enzymes	Needed to improve the FCR			
Pellet size (mm)	Mash	2	2-5	2-5
Floating pellets (min)	N/A	≥ 2	≥ 2	≥ 2
Packaging labels	Company address, manufacturing and expiry date			
Packaging size	5 kg,10 kg, 20 kg, 50 kg, etc.			
Packaging material	Must be airtight			
Acidifiers	Preferred			
Premix (vitamin and mineral)	Mandatory			

Courtesy of ESP aquaculture working group 2012-2013.

Table 3. Authenticated feed suppliers in Kenya

Company name	Address	Region/Location	Director/Contact (tel no.)
Sigma Feeds Ltd. Co.	P.O. Box 18138 Nairobi	Isinya /Namanga Road, Kajaido	Shah Kirtesh +254-0733600895
Uga Fish Feeds Kenya Ltd.	P.O. Box 31833-00600 Nairobi	Industrial Area, off enterprise road	Dr. E. Onyango +254-020-2634081
Economy Farm Products Kenya Ltd.	P.O. Box 64983-00620 Nairobi	Nanyuki Rd. Industrial Area, Nairobi	John Gathongo +254-00202013366
Maisha Bora Fish Feeds Ltd.	P.O. Box 60803-00200 Nairobi	Kikuyu, Nairobi	Gilbert Gathuo +254-020-2511824
Thoyu Feed Ltd.	P.O. Box 4491-20100 Nakaru	Sungura road Industrial Area	Priscilla Nduta +245728427898
Kwality Fish Feeds Limited	P.O. Box 71-00200- Nairobi	Off Ruiru Kiambu Road	Peter Cotti +254-721274386
Cottage feed industries			
Othaya Fish Feeders S.H.G	P.O. Box 82 Othaya	Othaya	Moses Ndungu +254-0726849170
Chumara Fish Feeds	P.O. Box 353 Chuka	Chuka	John Marangu +254-0735628971
Bidii Fish Farmers S.H.G	P.O. Box 215 Luanda	Luanda- Emuhaya	George Ambuli 0723117706
Osifeeds Ltd.	P.O. Box 134-00606 Nairobi	Kajiado	Susan Kisoso 0720751859
Zibag Fish producers & Processors	P.O. Box 1333, Nyahururu	Nyandarua	DFO Nyahururu 0721622474
Hesao Integrated Fish Farming Organization	P.O. Box 3844 Kisumu	Nyalenda B	Richard Okongo 0722 620169

Courtesy of ESP aquaculture working group 2012/2013.

organisms. Commercial fish feeds for tilapia usually contain 24-28% crude protein (Liti et al., 2006) but are too expensive for most farmers. Therefore, most farmers prefer locally mixed feeds, such as a combination of 76% rice bran and 24% fish meal, which is a mix of dried freshwater shrimp *Caridina* spp., or maize bran, sometimes with some Omena *Rastrineobola argentea* meal added (Ngugi et al., 2007). Based on studies by Liti et al. (2006), fish fed maize or wheat bran grew significantly faster than those fed rice bran. Maize bran is better than wheat bran because of lower levels of fiber.

Due to the low quality of fish feeds in the Kenyan aquaculture market, the ESP nutrition team, together with other aquaculture stakeholders, established a vetting process for fish feed manufacturers. To date, 15 fish feed firms have been approved, but further survey efforts are under way to identify more firms (Table 3).

Current Status of the Seed Fish Sector

Insufficient availability and quality of fingerlings for stocking are key constraints for the development of Kenyan aquaculture. In addition to the escalating demand for African catfish *C. gariepinus* fingerlings for stocking fish ponds, this species is also used as bait fish in capture fisheries, leading to increased demand every year (Ngugi et al., 2007). As of 2007, the Fisheries Department estimated that the annual demand for catfish fingerling in Lake Victoria was 10 million/y for aquaculture and 18 million/y for bait (Ngugi et al., 2007). Today, the total demand for both catfish and tilapia fingerling is estimated at 100 million yr^{-1} (Charo-Karisa and Gichuri, 2010). Despite governmental efforts to improve existing fish breeding centers, this huge annual demand for fingerlings cannot be attained unless further development by the private sector. In addition, the quality of the fingerling supplied needs to be ensured. To achieve good quality seed fish, aquaculture experts have encouraged measures to obtain same-sex fingerlings using sex reversal and hybridization techniques. However, such initiatives are still unpopular among fish farmers due to the technical knowledge and facilities required. These are some areas that private investors could link to support fish farming in Kenya. So far, the Kenyan government through the aquaculture working group which brings together researchers, fisheries officers, fish farmers, Kenya Bureau of Standards (KBS), and other stakeholders has authenticated fish hatcheries nationwide and are in the process of drafting seed fish quality standards, which are expected to solve problems of substandard seed fish in the aquaculture market.

Challenges in the Kenyan Aquaculture Sector

Unfortunately, after many years of fish farming in Kenya, the country is still suffering from basic challenges. The Kenyan aquaculture industry suffers from limited knowledge of aquaculture investment (Ngugi and Manyala, 2004) and lack of information on the economic performance of various fish farming systems (Kaliba et al., 2007). More importantly, the inadequate supply of certified quality feed and seed fish has been a longstanding hurdle to the growth of aquaculture. Farmers have given up fish farming because they run into huge losses after stocking their ponds with low-quality fingerlings and substandard feed. Other factors affecting the growth of aquaculture include lack of a comprehensive aquaculture policy, poor extension services, lack of robust need-based research coupled with low funding, lack of investment by the private sector, and unfocused promotion of aquaculture through many institutions (Gitonga et al., 2004). Indeed, improvements in fish culture systems, such as increasing pond productivity, introducing other efficient systems, and developing a sustainable mechanism for production and distribution of pond inputs, are challenges that still need to be addressed. With the explosive interest in fish farming stimulated by the ESP, new challenges from environmental pollution, biosecurity, and the spread of diseases are likely to emerge in the near future.

Opportunities for Present and Future Aquaculture Development

The major problem with marine fish larviculture is the lack of proper food that contains all the essential nutrients required by fish larvae, which has led to mass mortalities up to 100% (Sorgeloos, 1980). Recently, a great opportunity has presented itself on the Kenyan coast, thanks to the permanent establishment of a population of *Artemia*, due to cooperation between the KMFRI and the Belgian government (Mremi, 2011; Kapinga, 2012; Ogello, 2013). *Artemia* is a live food with excellent nutrition for the development of marine fish larvae (Sorgeloos, 1980) and is small enough for larval fish to ingest (Sorgeloos et al., 1995). This is an excellent opportunity to increase food production and create employment through enhancing emerging mariculture initiatives, such as mullet, milkfish, and prawns, which seem to perform better in ponds than in natural waters (Bardach et al., 1972). Culture of shrimp and shellfish, such as mussels, oysters, and abalone, has not been initiated. The global estimate of the annual *Artemia* cyst market to feed fish and shellfish is over 2,000 tons, costing about 65 USD/k (Dhont and Sorgeloos, 2002). Shrimp hatcheries consume 80-85% of total sales, mainly in China, Southeast Asia, Ecuador, and other Latin American countries. Kenya can emulate the success of Vietnam, which has become one of the leading traders in *Artemia* cysts in the world market. Indeed, *Artemia* farming could be a gold mine. Kenya has the opportunity to exploit this opportunity and join other world leaders in the *Artemia* cyst trade.

Seaweed farming

Kenya has a relatively lengthy coastline endowed with a wide variety of habitats for seaweed communities, much more so than other regions of tropical Africa (John and Lawson, 1997; Bolton et al., 2003). Kenyan seaweeds are relatively well documented (Bolton et al., 2007) in a checklist that includes a total of 386 species (214 red algae, 116 green algae, and 56 brown algae), plus an additional 19 intraspecific taxa (Bolton et al., 2007). Data on the Indian Ocean indicate that Kenya produces a group of seaweeds different from Tanzania, Madagascar, Mozambique, and the Indian Ocean coast of South Africa (Bolton et al., 2003, 2007). Through the KMFRI, research on seaweeds is currently ongoing, and great potential exists in marine-based seaweed farming. Indeed, the commercial viability of seaweed farming has a market potential that could put Kenya on par with countries such as Tanzania and Zanzibar. The growth of seaweed farming was recently captured in one of the Kenyan leading newspapers. The Standard reported in July 2013 that farmers along the Kenyan coast are embracing seaweed farming. This is a shift from fishing, where stocks have dwindled over recent years. Seaweed sells for \$141.20 ton^{-1}, which has enabled local communities to improve their lives tremendously.

Indigenous freshwater aquaculture species

Before the introduction of Nile perch *Lates niloticus* in Lake Victoria, two tilapia species (*O. esculentus* and *Oreochromis variabilis*) and other fish, such as *Bagrus docmac*, *Labeo* spp., *Synodontis* spp., and *Protopterus* spp., were the main species in the Lake Victoria fishery (Kudhongania and Kitamwebwa, 1995). Today, most of these lucrative indigenous species have been eliminated by Nile perch (Ogutu-Ohwayo, 2004). Spirited efforts have been made by the KMFRI to restore some of these native fish species through aquaculture initiatives. Recent cage culture trials of the native *O. esculentus* and *O. variabilis* in Lake Victoria showed that native fish can perform well in aquaculture systems. In addition, the KMFRI has pushed attempts to domesticate and culture *Labeo victorianus* at Sangoro and Kegati research stations. Even though little success can be reported, research efforts are on course. Local communities still recognize and attach strong economic value to the native fish species, and we believe this is another lucrative opportunity yet to be exploited in Kenyan aquaculture.

Conclusion and Recommendations

The much reported decline of capture fisheries in Kenyan natural waters is a clear indication that aquaculture needs to alleviate the burden of fish shortages. The great potential of Kenyan aquaculture cannot be emphasized enough. Indeed, the increased interest in aquaculture following the ESP is a testament that much more can be achieved when stakeholders work together. The successful development of sustainable aquaculture lies in the promotion of aquaculture as a viable investment opportunity whereby potential investors identify opportunities to make economic gains in a “win–win” fashion. As noted here, the marine sector harbors the most lucrative opportunities and should be given special focus. Other farming systems, such as integrated fish farming and cage culture, are underappreciated assets for present and future development of sustainable aquaculture in Kenya. A need exists to create linkages and collaboration among all stakeholders (research institutions, universities, fish farmers, nongovernmental organizations (NGOs), civil society, government officials, and policy makers) by creating a strong forum for exchange of information. Mechanisms must also be developed to link small farmers to local, urban, regional, and global markets. Rural schools are needed to educate farmers and strengthen their capacities to adopt new aquaculture technologies. Governments must create an environment to enable the private sector to invest in strategic areas. Specific and pragmatic policies should be tailored to effectively respond to local aquaculture conditions instead of impractical highly intensive aquaculture systems.

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