Exploring enabling factors for commercializing the aquaculture sector in Kenya

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Acronyms and Abbreviations

ABDP	The Aquaculture Business Development Programme
CASK	Commercial Aquaculture Society of Kenya
DFID	Department for International Development
EAC	East African Community
ESP	Economic Stimulus Package
FAO	Food and Agriculture Organization of the United Nations
FFE	Fish Farming Estates model
FFEPP	Fish Farming Enterprise Productivity Program
FTA	FoodTech Africa
GOK	Government of Kenya
IFAD	International Fund For Agriculture Development
IIM	Integration into the input market
IOM	Integration into the output markets
KES	Kenya Shillings
KMAP	The Kenya Market-Led Aquaculture Programme
KMFRI	Kenya Marine and Fisheries Research Institute
NGO	Non Governmental Organization
PVC	Polyvinyl Chloride
RAS	Recirculation Aquaculture Systems
SSA	Sub-Saharan Africa
USAID	United States Agency for International Development
USD	United States of America Dollars

Executive Summary

The aquaculture sector is expanding worldwide, driven by the blue economy and blue growth policy, based on principles of smartness, inclusiveness and sustainability, and the need to provide food and nutrition security to an ever-growing population. This trend is still at an early stage in Kenya. This report explores core enabling factors for commercialization of the aquaculture sector in Kenya, based on a structured household survey and a qualitative literature survey and through application of an analytical food system approach that includes the value chain and consumers. First, nine commercialization categories were identified: high, medium and low commercialization levels for each of cage, pond and tank aquaculture production systems. Second, an analytical farm household survey of 300 farmers was conducted in the counties of Kiambu (60), Kakamega (80), Siaya (80), Nyeri (45) and Kirinyaga (35) to analyse enabling factors in each of the nine commercialization categories. The enabling factors explored are income (in Kenyan Shillings [KES]), fingerling production [numbers], fish feed (floating pellets [tons]), transport (% of farmers who have their own transport), market outlets (% per outlet category), share of fish meals consumed per household (%), risk taking/aversion (perception ranking) and trust in government (perception ranking). Third, a qualitative literature survey was conducted to review best practice in commercialization of the aquaculture sector in Kenya. The analyses show that enabling factors differ substantially across the nine categories. The main motivations of pond farming are to ensure food and nutrition security; it is deemed successful when costs can be covered by generated income, even without further investments to commercialise. Pond farming is therefore the least commercialized segment of the aquaculture sector, although it has obtained the most subsidies in the past. Cage farming is expanding substantially in Lake Victoria, and regulations and planning to monitor environmental impacts are urgently needed. Given the high number of new investors, cage farming is expected to contribute significantly to aquaculture supply in the future. Tank farming is a highly commercialized segment that depends on appropriate technology, which is expensive and accessible only to a few fish farmers. However, the efficiency in use of water, feed and land; the reduced risks of losses; and the possibly low distance to urban markets can make this segment a critical supplier of fish to a large consumer group in the future. Overall, it is advised that future investors in aquaculture in Kenya should be aware of the specific enabling factors of each category and should target the most critical enabling factors.

1 Introduction

Total global fisheries and aquaculture production was 171 million tons in 2016, of which aquaculture contributed 80 million tons and provided consumers with an average of 20.3 kg per person (FAO, 2018). Commercialization of aquaculture is growing in various parts of sub-Saharan Africa (SSA), including Kenya. This trend is explained by factors such as growing population, improvement in socioeconomic conditions resulting in rising demand for fish by a rapidly emergent middle class, and increasing prices of wild-caught fish (Kaminski *et al.*, 2018; Obwanga *et al.*, 2018). Commercialization is worth exploring to see if it can ensure viability of the aquaculture sector in Kenya; farmers will be less vulnerable to the disruption that occurs when the support from aid ends. Aquaculture development is linked to the growing interest in blue economy and blue growth policies, based on principles of smartness, inclusiveness and sustainability, as development strategies to promote food security and decent livelihoods in Africa.

Since 1960, the Government of Kenya (GoK) and donor-funded development organisations have promoted aquaculture sector development. These efforts target development and implementation of policies that encourage private investment to drive the sector's growth (Ridler and Hishamunda, 2001). One of the government programmes is the Economic Stimulus Programme (ESP), which was to jumpstart the Kenyan economy towards long-term economic growth in 2009/2010. It included the establishment of the Fish Farming Enterprise Productivity Program (FFEPP) which, although designed to increase production and commercialization of fish farming through government-subsidised financial support (Mwamuye *et al.*, 2011), mostly supported small-scale farmers who then tended not to make the transition to commercial fish farming and became vulnerable when support ended. The GoK also supports different programmes aimed at reducing poverty and increasing food security.[1] For instance, Food and Agriculture Organization (FAO) is funding the two-year Aquaculture Business Development Programme for Kenya[2], which began in June 2019 and supports, for instance, fish production, value addition, income generation and employment along the aquaculture value chain (Government of Kenya, 2017).

Since 2010, the blue economy has been promoted as a way to achieve smart, sustainable and inclusive growth in Kenya, bringing new and innovative opportunities for initiatives linked with water and sea activities. Aquaculture value chain activities contribute to the blue economy and benefit from the increased opportunities to obtain substantial investment. Besides supplying fish and fish products, the aquaculture sector contributes to socioeconomic and environmental sustainability (Government of Kenya, 2018). The inaugural Blue Economy

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[1] Donor-based interventions in fish farming in Kenya include 1) research capacity-building and field trials by American Peace Corps NGO, USAID-supported Collaborative Research Support Program and AquaFish Innovation Lab, 2) Customised extension information and materials by FAO and African Sustainable Trust Fund, and 3) Fish farming in they tilapia fish value chain and capacity-building by European Union, Aller Aqua training on feed formulation, and the Kenya–German–Israel Trilateral Project.

[2] This programme focuses on counties with high levels of aquaculture activity and production, as well as availability of sectoral infrastructure, water, marketing potential, processing and support by research. In the first phase, the project supports individual small-scale farmers and aquaculture associations, groups or cooperatives in six counties (Migori, Homa Bay, Kakamega, Meru, Kirinyaga and Nyeri). In the second phase, nine counties (Kisii, Kisumu, Tharaka-Nithi, Machakos, Siaya, Busia, Embu, Kajiado and Kiambu) will be supported.

Conference, held in Kenya in November 2018, was organised to stimulate investment in the blue economy by at least €40 million for the aquaculture sector, including 1) construction of a hatchery at Victoria Farm in 2019, with a permit to produce 10,000 tons of fish for sale by 2020; by April 2018, the farm was producing 200,000 fingerlings a week (Victory Farms Limited East Africa)[3], and 2) accelerated support to develop African aquaculture value chains, including production, fish processing and storage capacities in the blue economy industries. The GoK is showing high commitment to the blue economy, by its establishment of a new State Department for Fisheries and Blue Economy, part of the Ministry of Agriculture, Livestock Development and Fisheries.

However, despite these efforts and investments, the growth of sustainable commercialization in the aquaculture sector in Kenya has not kept pace with that of other leading countries in SSA. The leading aquaculture-producing countries in SSA with commercial growth in the value chain are characterised by large-scale, market-led investment that creates stability in supply throughout value chains (e.g. Ghana, Egypt, Nigeria). As a consequence, investment in capital-intensive technologies such as cage culture or land-based units (recirculation aquaculture systems [RAS]) and research on genetic improvements of cultured species (Kaminski *et al.*, 2018; Obwanga *et al.*, 2018) are expected to influence future commercialization possibilities.

Against this background, in this study the overall aim is to explore core enabling factors for commercialization of the aquaculture sector in Kenya. In order to address this overall aim, three main research questions have been defined:

- What commercialization categorisation can be applied to fish farms in Kenya?
- What can be learned, applying a food system approach, about the main enabling factors for each of the commercialization categories from best practices?
- What specific investments in aquaculture in Kenya can enhance best practice in the commercialization of fish farms to benefit value chains and the food system at large?

Chapter 2 of this report introduces and explains an analytical food system framework that was developed for the survey of the aquaculture sector in Kenya, and the methodological approach is described. In Chapter 3, an overview of developments, production and consumption in the aquaculture sector in Kenya is provided. Chapter 4 presents a categorization of aquaculture farms and the outcomes of a household survey conducted of 300 aquaculture producers in Kenya in August 2018. In Chapter 5, investment in the aquaculture sector in Kenya is described. Chapter 6 discusses and analyses institutional governance, and this is followed by a review of the socioeconomic, institutional, environmental and climatic enabling factors in Chapter 7. In Chapter 8, the discussion ends with a qualitative assessment of the different categories based on the enabling factors. In the concluding remarks of Chapter 9, some key knowledge gaps are listed for follow-up.

[3] https://www.theeastafrican.co.ke/business/Cage-farming-Lake-Victoria-boosting-fish-stocks/2560-4396034-fklb5w/index.html

2 An analytical food system framework

Chapter 2 of this report introduces and explains an analytical food system framework that was developed for the survey of the aquaculture sector in Kenya, and the methodological approach is described. In Chapter 3, an overview of developments, production and consumption in the aquaculture sector in Kenya is provided. Chapter 4 presents a categorisation of aquaculture farms and the outcomes of a household survey conducted of 300 aquaculture producers in Kenya in August 2018. In Chapter 5, investment in the aquaculture sector in Kenya is described. Chapter 6 discusses and analyses institutional governance, and this is followed by a review of the socioeconomic, institutional, environmental and climatic enabling factors in Chapter 7. In Chapter 8, the discussion ends with a qualitative assessment of the different categories based on the enabling factors. In the concluding remarks of Chapter 9, some key knowledge gaps are listed for follow-up.

2.1 An overall analytical food system framework for the aquaculture sector in Kenya

The green and blue economies require food production systems to be smart, sustainable and inclusive (European Commission, 2010, 2012; Government of Kenya, 2018; Moffitt and Cajas-Cano, 2014; Soma et al., 2018a), 2019). Smart growth refers to the development of an economy based on knowledge and innovation; sustainable growth refers to promotion of a more resource-efficient, greener and more competitive economy; and inclusive growth refers to the fostering of high employment in an economy based on economic, social and territorial cohesion.

A food system approach entails analysis of the outcomes of the system (e.g. food and nutrition security, socioeconomic and environmental outcomes) and how these can be improved through policy incentives or business investments that influence or change relationships between actors/stakeholders in the value chain (including consumers) (van Berkum et al., 2018). It suggests that if the aim is to ensure smart, sustainable and inclusive food systems, it is not sufficient to look at food production only. Even an investigation of the whole value chain – food production, transport, storage, trade, processing, transformation, retail, provisioning and consumption – will not necessarily contribute to sufficient outcomes. This is because beyond the value chain there are related activities affecting how robust, reliable and resilient (3R) value chains are, including institutional governance and innovation systems. External to all these activities, socioeconomic (e.g. social welfare) and environmental (e.g. environmental security) enabling factors influence the quality of factors of the value chain.4 The food system approach therefore provides a holistic view and the opportunity to address the actual factors that can contribute to improved outcomes.

Based on insights drawn from existing food system frameworks (e.g. van Berkum et al., 2018), an analytical food system framework was designed in this study to analyse the aquaculture value chains in Kenya (Figure 1). The variables listed in the figure were investigated during the structured household survey described in Chapter 3.

[4] During a workshop in September 2018, partners of the project discussed the specifics of a food system framework for the 3R Kenya project (3R Kenya, 2018).

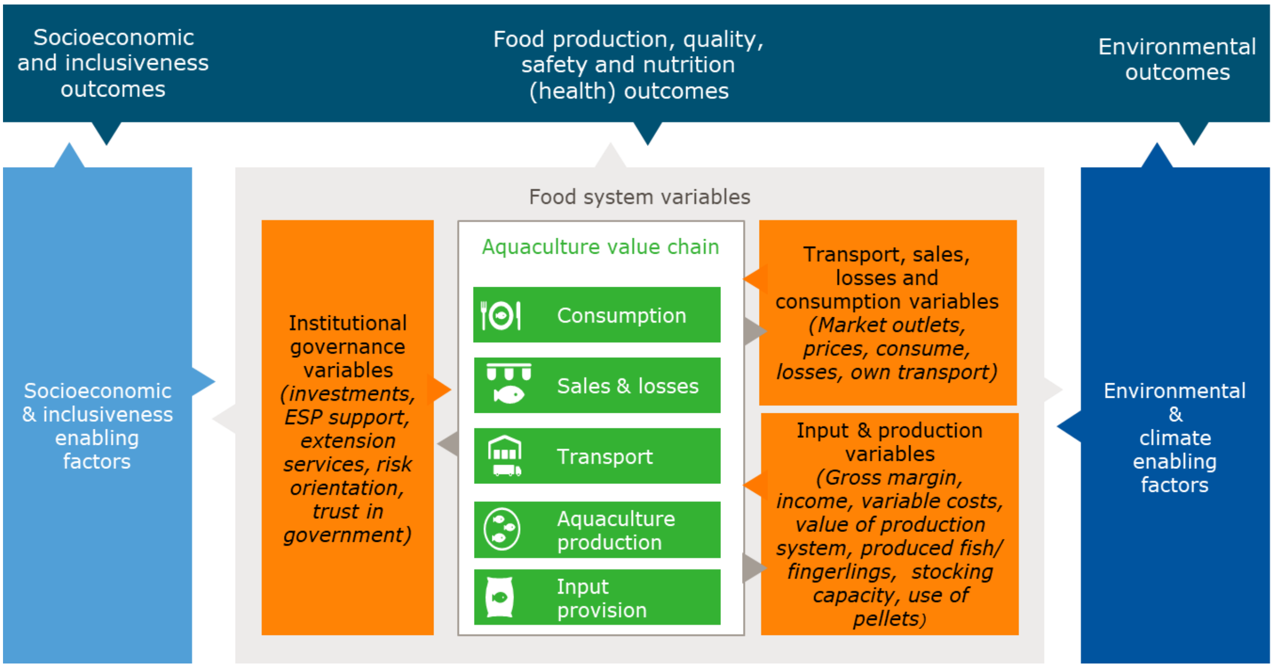

Figure 1: An analytical aquaculture food system framework, including factors to be analysed by the structured household survey

2.2 Methodological approach

The aquaculture food system approach used in this study carried out three levels of analysis:

- A **literature review** on the aquaculture sector in Kenya contributed to several parts of this report, including the aquaculture sector in Kenya overview (Chapter 3), aquaculture production systems (section 4.1), investment in aquaculture (Chapter 5), institutional governance (Chapter 6), socioeconomic, inclusiveness, environmental and climate enabling factors (Chapter 7) and discussion (Chapter 9). The literature review was supported by insights offered by stakeholders, for instance in workshops with panel discussions on aquaculture in Kenya (Koge *et al.*, 2018, 2019).
- A **structured household survey** was conducted by interviewing farmers operating in specific aquaculture commercialization categories, in order to analyse relevant enabling factors of the aquaculture food system in their transformation towards robust, reliable and resilient aquaculture activities (Chapter 4).
- **A review of commercialization categorisation.** The review of categorisation approaches was conducted to define proper commercialization categories for this report (section 2.3).

The literature review. The literature consists of grey and scientific papers, reports and books. Searches were conducted in Scopus and Google Scholar, and relevant literature was identified through the 'snowball effect' by consulting experts both inside and external to the project.

The structured household survey. A structured survey was undertaken of 300 small-, medium- and large-scale aquaculture farmers in Kenya. Based on a sampling procedure with multiple indicators that were recommended by stakeholders (Koge *et al.*, 2018) (when selecting areas, the wishes to include locations where Farm Africa and IFAD project (phases 1 and 2) have been operational, as well as locations close to Nairobi and Lake Victoria, were taken into account), data were collected in the counties Kiambu (60), Kakamega (80), Siaya (80), Nyeri (45) and Kirinyaga (35). See locations in Figure 2.

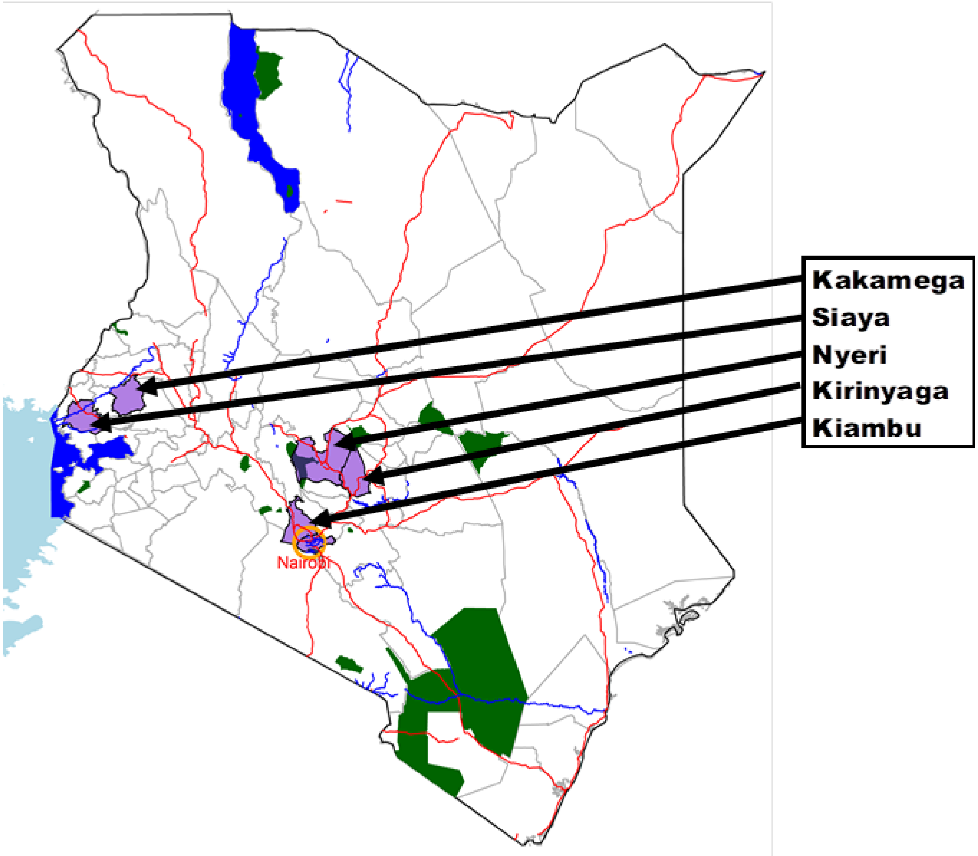

Figure 2: Map of areas investigated

Source: Hennen, 2019

The counties were selected based on recommendations of an aquaculture stakeholder platform in Kenya (Koge *et al.*, 2018). The criteria used included the need to include diversity across locations (close to Nairobi and to Lake Victoria), as well as diversity across characteristics such as 1) value chain enabling factors such as supply to market (e.g. on-farm sale, local market, urban market, export), 2) environmental constraints (e.g. issues of water shortage, biodiversity loss, pollution), and 3) need for infrastructure (e.g. distance to market, own transport possibilities, cooling). Based on this advice, 300 farmers were selected, of which most had aquaculture systems with ponds (199), followed by cages (81) and tanks (20).

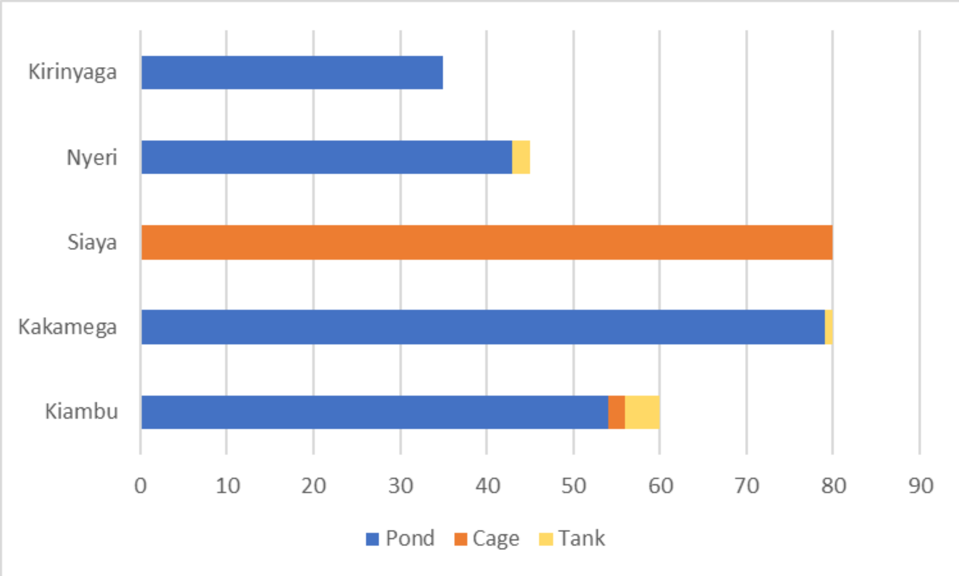

Figure 3: Number of farmers operating ponds (199), cages (81) and tanks (20) in each of the five areas (Kiambu, Kakamega, Siaya, Nyeri and Kirinyaga)

The review of commercialization categorisation. In analysing the outcomes of a highly differentiated aquaculture system in Kenya and how these can be improved by policy incentives or business investments that influence or change relationships between actors/stakeholders in the value chain (including consumers), it is crucial to understand how subsectors differ. A straightforward way to categorise the aquaculture sector in Kenya is to distinguish between the three main production systems: cage, ponds and tank farmers. However, such categorisation is not specific enough given the diversity within each category based on location, size and specific challenges and opportunities.

In the literature, the aquaculture sectors in different countries have been categorised in several ways. For instance, of particular interest to this study are surveys of commercial cage farms conducted in Lake Volta (Ghana) (Kassam, 2014, p. 5; Kaunda *et al.*, 2010; Rurangwa *et al.*, 2015). In these studies, the main actors in aquaculture production are:

- large-scale commercial cage farms, producing over 5,000 tons per year per farm
- medium-scale cage farms, producing 50–1,000 tons per year per farm
- small-scale cage farms, producing 1–50 tons per year per farm.

Although many African countries share core properties and can learn from each other to tackle similar challenges in recent aquaculture developments, the scales and contexts differ. Compared with, for instance, Ghana which use foremost cage system, Kenya has a larger share of small-scale farms using pond systems, which nevertheless could be considered commercial given that they are independently operating without government support and do have a business plan (Frimpong and Anane-Taabeah, 2017; Ngugi *et al.*, 2017).

In a recent study focusing on small-scale commercial aquaculture in the East African Community (EAC), small-scale commercial fish farming was categorised for the industry development organisation Msingi, which supports growth of competitive industries, including aquaculture (van Duijn *et al.*, 2018). The focus was on individual farmers who produce less than 50 tons per year (although group production for this category could be above 50 tons per year). The small-scale commercial fish farming subsector within aquaculture was defined as having the following characteristics:

- A small-scale commercial fish farm is managed as a for-profit business by either an individual or a group (e.g. a cooperative).
- The individual or group invests capital in the enterprise.
- Cash returns on investment are the main criterion of success.

Another recent assessment (Farm Africa, 2018, 2019) stratified small-scale commercial aquaculture farms into three (AAA, AA, A) categories based on productivity according to five elements: site, level of production, investment, income, and business management. As business success depends on each of these factors, the total score is a combination of scores in each category. In particular, towards the end of 2017, Farm Africa formed categories based on data gathered during their training programme with farmers:

- AAA category farmers (>75% score) are **high-performing farmers**. With good business management skills, these farmers know how to run their farms, having invested intensively in their aquaculture businesses, and achieved higher production levels. They intend to improve their margins by adopting improved farmer practice, planning and production and are thus driven by marked-led initiatives.

- AA category farmers (40–75% score) are **mid-adopting farmers**. While they often run medium- to large-scale enterprises, AA category farmers engage in mixed-method production practices and often combine high-quality inputs with green water production and homemade feeds. This group practises semi-intensive production with limited investment in equipment and other aspects of their businesses, not always considering their farm as a business endeavour.

- A category farmers (<40% score) are **slow-adopting farmers.** With poor site location, lack of access to necessary resources such as water, and limited access to equipment such as weighing scales, A category farmers make no or limited investment in their businesses or in high-quality inputs. Consequently, they sometimes encounter inbreeding problems. They use homemade feeds and green water with no proper pond fertilisation and rely primarily on nature to produce fish, taking little action to influence their margins.

Categorisation can be further specified by formulas developed by Riwthong *et al.* (2015, 2017). In their approach, the commercialization level is based on a composite score of input and output commercialization, considering the integration of farmer production systems into both input and output markets.

A farmer's integration into the input market (IIM) is defined as:

$$= \frac{Value\ of\ variable\ inputs\ bought}{Total\ value\ of\ variable\ inputs\ used}$$

A farmer's integration into the farm output markets (IOM) is defined as:

$$= \frac{Gross\ farm\ output\ sold}{Total\ gross\ value\ farm\ output}$$

By taking the average of these two indicators (IIM+IOM/2) from the farm survey data, farmers can be categorised into commercialization levels of high, medium and low commercialized farmers. For the methodology of this survey, this categorisation is used.

First, the expected trends for each of some selected indicators are suggested for each category (Table 1). These are confirmed or not by the outcomes of the household survey (Table 6). The indicators are part of the analytical aquaculture food system framework and are selected to investigate core characteristics of each commercialization category.

Table 1: Selected food system indicators as enabling factors for commercialization of the aquaculture sector and expected trends across the commercialization categories in Kenya

Selected food system indicators	**Commercialization level of cage, ponds, tanks**		
	High	Medium	Low
Income (KES)	High	Medium	Low
Fingerlings produced (number of pieces)	High	Medium	Low
Inputs (floating pellets)	High	Medium	Low
Market outlets (% per outlet category)	Larger variety outlet categories	Medium variety outlet categories	Smaller variety outlet categories
Transport (% of farmers with own transport)	Full access to own transport	Small share with no access to own transport	Medium share with no access to own transport
Share of fish meals consumed per household (%)	Low	Medium	High
Risk-taking/aversion (perception ranking)	Risk-taking	Medium	Risk-averse
Trust in government (perception ranking)	High	Medium	Low

3 The aquaculture sector in Kenya – An overview

To prepare for the food system analysis of the outcomes of the aquaculture system (e.g. food and nutrition security) in Kenya, this overview describes how the sector has developed and the particular characteristics of aquaculture production and consumption in the country.

3.1 Three historical phases

The development pattern of the Kenyan aquaculture sector can be classified into different historical phases: the introductory phase, the donor and government support phase, and the private sector–led phase, as illustrated in Figure 4 below.

<table>
<tr><td>1920</td><td>1930</td><td>1940</td><td>1950</td><td>1960</td><td>1970</td><td>1980</td><td>1990</td><td>2000</td><td>2010</td><td>2020</td></tr>
<tr><td colspan="4" rowspan="2">Introductory phase</td><td colspan="5">Donor and government support phase</td><td colspan="2">The private sector–led phase</td></tr>
<tr><td colspan="7"></td></tr>
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Figure 4: Historical phases of the aquaculture sector in Kenya

The introductory phase. Fish farming was introduced in Kenya in the 1920s by the colonialists, initially for sport fishing, and evolved to fish farming in static water ponds. Two fish farms were set up in 1948, the Sagana Fish Farm for warm-water species and the Kiganjo Trout Farm for cold water species, in order to produce seed for stocking of ponds, dams and rivers.

The donor and government supported phase. In the 1960s, fish farming was popularised by the GoK through the "Eat More Fish" campaign. The focus of policies and donors was mainly on food security, poverty alleviation and job creation in rural areas. Despite various forms of technical and financial assistance from several multilateral and bilateral donors and government involvement in seed supply and extension services, the subsector remained dominated by subsistence fish farming in ponds. Aquaculture was not seen by farmers as a commercial activity that could result in economic gains (Rothuis *et al.*, 2011), and many ponds were abandoned due to lack of inputs, mainly feed and seed, and poor harvests. Mariculture was introduced only in the late 1970s, with the establishment of the Ngomeni Prawn Farm as a pilot project (Rothuis *et al.*, 2011). In 2010 the ESP and the FFEPP played an important influencing factor to the aquaculture sector. As a result, in 2015 there were 60,277 ponds covering 1,808 ha (Opiyo *et al.*, 2018). (Box 1 provides some examples of donor-supported initiatives after 2010).

Box 1. *Examples of donor-supported aquaculture initiatives in Kenya*

- **Farm Africa's** Aqua Shops Project, funded by DFID, has developed a network of outlets in six locations in Western Kenya that provide fish feed and manure, technical advice and market linkages to up to 1,000 smallholder farmers interested in using the ponds to set up their own fish farming businesses.
- **Gatsby Foundation**, through Msingi East Africa, has identified aquaculture as a high potential sector to develop. It has conducted different market studies across the aquaculture value chain to investigate bottlenecks and investment opportunities (see more in van Duijn *et al.*, 2018).
- **The Aquaculture Business Development Programme (ABDP),** started in 2019 (see the footnote in the Introduction). This programme is supported by IFAD and targets smallholder aquaculture fish production.

The private sector–led phase. In 2011, following the publication of the new private sector policy by the Dutch Government, a study was carried out to explore business opportunities for Dutch companies to support the sustainable development of the Kenyan aquaculture sector (Rothuis *et al.*, 2011). The study confirmed the potential for aquaculture in Kenya. (See some Dutch-supported initiatives in Box 2.)

***Box 2.** Dutch-supported initiatives in Kenya*

- **FoodTechAfrica (FTA).** This is another public–private initiative partially funded by the Dutch Government. It was established in 2013, and since then an integrated aquaculture value chain has been established in East Africa that began in Kenya. Combining the strengths of Dutch agrifood companies, knowledge institutes, government agencies and their East African counterparts has contributed to the success of these developments. Kamuthanga fish farm in Machackos was the first farm to house a plug-in type of RAS technology adapted to East African conditions. Subsequently, other fish hubs operating RAS farms plan to follow soon. The first FTA fish hatchery is already operational with a production capacity of 2 million tilapia fingerlings per year, and a second one is about to start with an annual production capacity of 1.2 million YY male Tilapia (van Vliet, June 2019, pers. comm. Workshop. Nairobi). An aqua feed factory with a production capacity of 5,000 tons of feed per year has been constructed at Unga Holdings Limited, and different actors in the aquaculture value chain have been trained under this initiative (Rurangwa and van Duijn, 2018). In 2017, FTA contributed around 100 tons of fish to production in Kenya using RAS. With the expansion of the Kamuthanga fish farm, this production is expected to increase up to 250 tons annually in 2020 (ibid).
- **The Kenya Market-Led Aquaculture Programme (KMAP)** is funded by the Dutch Embassy in Nairobi and led by Farm Africa. It has engaged with the whole value chain to create a tipping point in the aquaculture industry, allowing the sector to grow and to create sustainable aquaculture businesses with increased production and market access. The focus of the project was on commercialization of pond farming.
- **Jambo Fish Kenya Ltd.** In line with the new Dutch policy, public–private initiatives are emerging. For instance, Jambo Fish Kenya Ltd was the first Dutch–Kenyan venture to be established in 2010 in Kiambu, Kenya, and to produce catfish fingerlings in ponds and RAS and table-sized catfish for the urban market. It has also been selling culture systems (RAS) and fish feeds from Skretting (Nutreco). Following a period of technical problems in Kiambu, Jambo Fish changed its name to Jambo Fish Western (K) Ltd and relocated near Mumias, Western Kenya, in 2013.

The GoK contributed to creating a business environment conducive to investment in key economic sectors, including commercial aquaculture. Since then, the development of the aquaculture subsector has benefited from a business approach, a flow of knowledge and technology, the introduction of intensive farming systems, accessibility to commercial feed and fingerlings, large capital ventures and partnerships of foreign investors with local entrepreneurs. New intensive production systems, namely the RAS and cage farming, have developed during this decade.

3.2 Aquaculture production

The Kenyan aquaculture sector is characterised by three main productions systems: ponds (earthen, lined), tanks (concrete, PVC, plastics, and cages (mainly low volume high density), each with different degrees of investment, management, intensification, commercialization and associated risks. Ponds are mainly concentrated in the Central, Rift Valley and the Western parts of the country, while tanks are in peri-urban areas and, for trout, in the highlands. Commercial cages are set up in the Kenyan part of Lake Victoria and in some water dams and reservoirs. Integrated aquaculture systems have also been introduced and include integrated cage-in-ponds (Charles *et al*., 2018) and aquaponics (Manyala *et al*., 2017).

Aquaculture production in Kenya increased markedly from 4,218 tons in 2006 to a peak in 2014 of around 24,000 tons (Figure 5). It had declined to 12,760 tons by 2017, which is attributed to a decline in volumes produced from ponds due to the end of the subsidies programmes. Because the prices are very different across markets and time, it is not a price trend explaining this drop. It is expected that the recent adoption of highly productive systems (RAS and cages) will increase production again in the years to come. These two systems have the potential to produce more fish per area compared to ponds.

Production is widely dominated by two warm-water fish species, the Nile tilapia (75% of total production) and the African catfish (18%), followed by two exotic cold water fish species, the common carp (6%) and the rainbow trout (< 1%) (Opiyo *et al.*, 2018). Production costs are €2.12–€2.35/kg for tilapia and €1.69–€1.90/kg for catfish (Kamstra *et al.*, 2014).

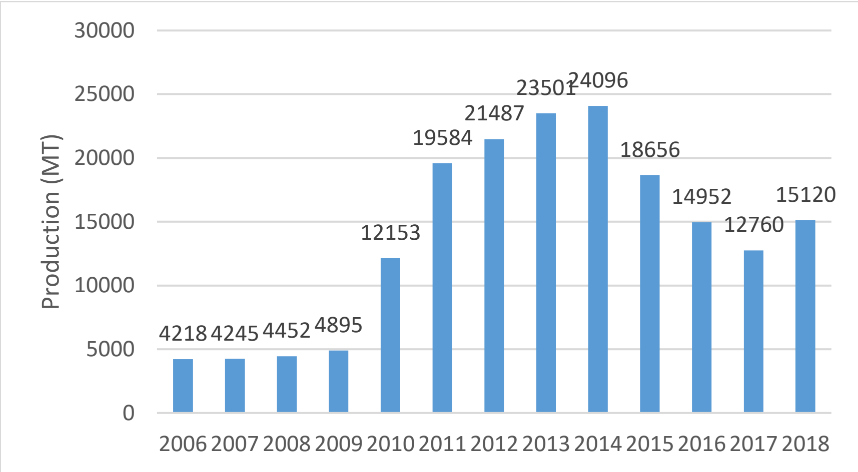


Figure 5: Aquaculture production (tons) in Kenya between 2006 and 2018

Monoculture of Nile tilapia is the most practised. Polyculture of Nile tilapia with the African catfish is often practised to control the prolific breeding of the former and increase production per unit pond area (Ngugi and Manyala, 2009). Nile tilapia, African catfish and carp are mainly cultivated under mixed sex semi-intensive systems in earthen, sometimes lined, ponds fertilised with organic manure, with the fish being fed supplemental feed. Trout are farmed intensively in commercial tanks and are fed with feed pellets. Extensive aquaculture pond systems depend on the natural productivity and the physical conditions of the water, with very little or no input and a low management level. Their productivity range is 500–1500 kg/ha/year (Kamstra *et al.*, 2014; Rothuis *et al.*, 2011). The production of trout in tanks is in the range 10–80 tons/ha/year. Attempts to culture some indigenous fish, such as the African carp and the Victoria tilapia have remained at experimental scale. Mariculture, despite its potential in the coastal area and in the Kenyan marine waters, has remained underdeveloped. This is also the case with the culture of ornamental fish, which has remained low (Rothuis *et al.*, 2011).

Kenya is generally characterised as a water-stressed country (Ogello and Munguti, 2016; Tramberend *et al.*, 2019), and available renewable water resources are insufficient to meet its water needs (Mekonnen and Hoekstra, 2014). A study called "Research FTA Production and system optimisation" aiming to compare the technical and financial feasibility of five fish farming methods based on production, operating costs and investments for Kenya has indicated the best farming areas for each type of aquaculture system (Kamstra *et al.*, 2014). Based on water availability and temperature, the western highlands region (the Lake Victoria region) is the most suitable zone for farming of tilapia and catfish in open systems (cages, ponds and flow-through). Water temperatures are in the range 24.1–28.8 °C within the Nyanza Gulf and 23.3–26.6 °C in the pelagic zone (Njuru, 2012).

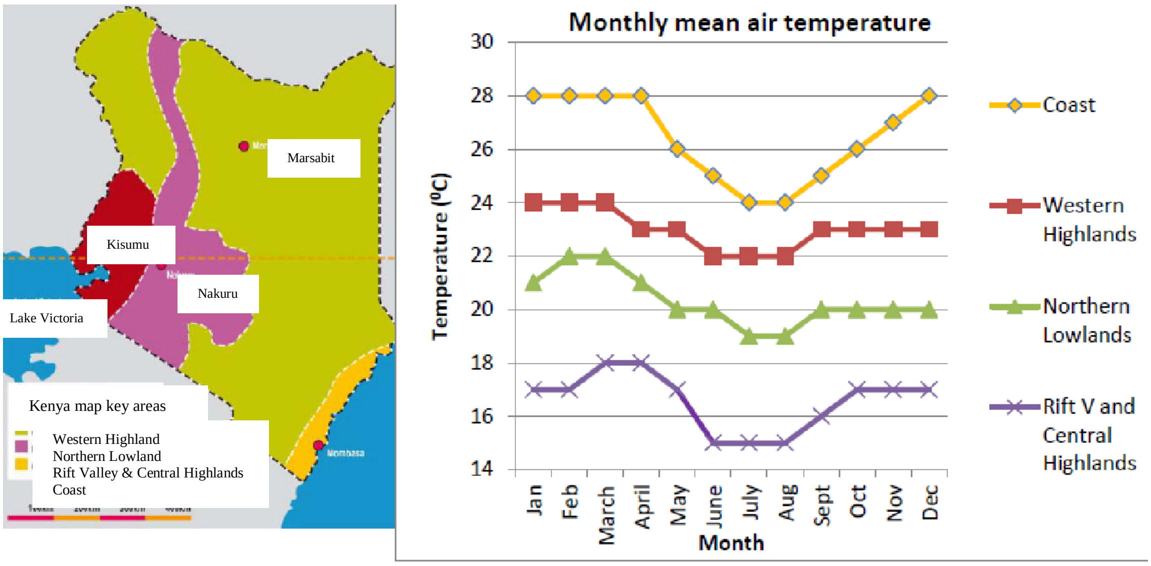


Figure 6: Four distinct climatic areas (left) and monthly mean air temperature variation (right) in Kenya

Source: adapted from Kamstra et al., 2014

In the central highlands and near Nairobi, the temperature is too cold to farm warm-water fish in outside systems. Air temperature at night, especially in the June/July season, can drop to 10 °C. The warmest part of the year is from December to March, when temperatures average the mid-twenties during the day. The mean maximum temperature for this period is 24 °C. Fish growth in open systems is slow and farming cycles can be long unless water is heated, which is only possible in semi-closed and closed systems. These areas are indicated for fish farming in RAS.

Semi-intensive pond systems, mostly producing Nile tilapia, have in the past been the major contributor to aquaculture in Kenya, with an average production of about 3 tons/ha/year, contributing more than 70% of total aquaculture production (Rothuis *et al.*, 2011; Turenhout *et al.*, 2013). After 2014, many ponds have been abandoned because of their lack of profitability and their low level of commercialization when the ESP stopped. This explains the downward trend in production observed since 2014 (Figure 5). The siting of most ponds across the country during the ESP did not consider the suitability for pond farming in relation to climatic conditions and water availability.

Intensive production of tilapia and catfish using exogenous feeding started during this decade by a few operators in the country. It can be practised in open systems (cages, ponds, flow-through tanks) without control over the culture environment as well as in semi-closed and closed systems such as RAS in controlled (climatic) culture conditions with aeration and water filtration. The production of such intensive systems is in the range 1–80 tons/ha/year (Rothuis *et al.*, 2011). This type of production is expected to grow, given the climatic constraints for both farmed fish species and the water scarcity in the country.

A new trend that is increasingly contributing to aquaculture production is the use of highly productive systems such as RAS and cages. Whether their contribution is already included in the national production data is not clear, as data are held by private commercial companies. Cage farms produced 3,180 tons in 2017.

Production from RAS in Kenya is increasing (Opiyo *et al.*, 2018). Kamuthanga Fish Farm, an established RAS farm through FoodTechAfrica, produced 45 tons of fish in RAS in 2017. An additional 60 tons of fish was produced during the same year in other linked fish farms based on sales of fingerlings and broodstocks. Kamuthanga Fish Farm projects it will produce 250 tons of fish per year in 2020 in RAS, after current expansion of the farm (Rurangwa and van Duijn, 2018). The RAS has the benefit of farming fish in an controlled optimal-temperature environment and uses less water compared to other systems per kilogram of fish produced, making it the best alternative in areas with water shortages and suboptimal water temperature.

Medium and large-scale commercial aquaculture uses highly productive intensive systems, such as intensive ponds, cages and RAS, to provide food and to contribute to employment and economic growth. RAS are stocked at high density: 5–20 fish/m^3 (Opiyo *et al*., 2018). Sometimes it can be as high as 110 fish/m^3, as shown at the Kamuthanga Fish Farm (Rurangwa and van Duijn, 2018). Production in RAS can achieve 10–15 tons of fish per 100 m^3 water under controlled conditions and good management. Opiyo *et al*. (2018) has reported that eight farms are operating RAS in the form of hatcheries and grow-out farms in Kenya, either as standalone systems or integrated in horticulture greenhouses, mainly near urban areas.

The first pilot cage farming dates back to 1980 in Kenya, but was not followed by commercial enterprise until a farm was established in 2005 by Dominion Farms Ltd in the rice irrigation dam at the Yala river in Western Kenya (Blow and Leonard, 2007). Intensive commercial cage culture started in 2013 and is currently practised in five riparian counties (Migori, Siaya, Homa Bay, Busia and Kisumu) (Njiru *et al*., 2018). Stocking density in the cages averages 60–250 fish/m^3 with cage sizes of 8–125 m^3 (Njiru *et al*., 2018). The production cycle is about eight months. Production data collected from cage firms indicate production of 3,180 tons in 2017, which was about 25% of total aquaculture production in Kenya in that year (ibid.).

According to FoodTechAfrica (2014), a choice of production system based on sustainability issues favours RAS over cage farming in relation to waste production, water use, escapee risk, use of energy and chemicals. Cage farming results in water pollution and may come under scrutiny in the near future.

Fish consumption. There is a continual structural deficit in Kenyan fisheries production. Fish consumption in Kenya has declined from 6.0 kg/capita in 2000 to 3.4 kg/capita in 2010, rose to 5.0 kg/capita in 2015 (Turenhout *et al.*, 2013), but in 2018 was as low as 4.3 kg per capita (Farm Africa, 2018). This is slightly below the average fish and seafood consumption in EAC (4.7 kg/capita/year) (Rothuis *et al.*, 2014), SSA (8.6 kg/capita/year) (FAO, 2018) and worldwide (20.2 kg/capita/year). The demand for fish in SSA, as driven by the trend of diet shift to fish and by economic and demographic growth, outstrips supply (Tran *et al.*, 2019). Reliance on capture fisheries and semi-intensive pond-based fish production has led to a freshwater fish deficit in Kenya. Imports of fish from the EAC region (mainly from Uganda) and from China are growing and are likely directly and indirectly absorbing demand for fish, curtailing local supply and placing downward pressure on fish prices (Lattice Research, 2016). In order to guarantee safe fish and fishery products from source to market, the GoK has put legislation in place. The legal framework covers the complete value chain (FoodTechAfrica, 2016). With stagnant, even declining, fisheries and a growing population with increasing appetite for fish, the fresh fish supply gap is likely to increase in the future unless substantial production is achieved through adopting intensive fish production systems in a responsible manner.

4 Findings across nine aquaculture commercialization categories in Kenya

In this section, the results of the structured household survey are provided. First, the sample characteristics are provided, including the outcomes of the categorisation analysis, household characteristics and share of fish species produced per category. Thereafter, as pointed out in Figure 1, relevant variables to an analytical aquaculture food system framework are analysed (including aquaculture production system, sales and losses, inputs, transport, consumption and institutional governance). The results of the household survey provide information about each category of indicators listed in Table 1.

4.1 Estimated characteristics across the nine categories

Results of farmer categorisation into nine sub-segments. Within each production system, some farmers are more commercialized than the others. Following the categorisation strategy explained in section 2.2., nine commercialization categories have been identified (reference numbers in the last column in Figure 7.). As explained in section 2.2, this categorisation is adopted from Riwthong *et al.* (2017), and results of the categorisation are based on selected information from the 300 farmers surveyed.

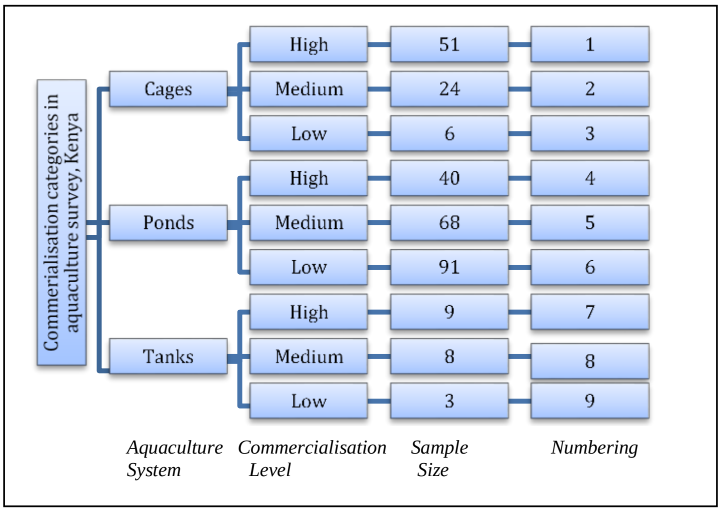


Figure 7: Overview of nine commercialization categories across aquaculture system, commercialization level, sample sizes and numbering used as reference in this report

The samples of pond farmers are large enough to be representative of this category of fish farmers. Because some of the other samples are rather small, including all tank samples and the low commercialized cage farming sample, they cannot be claimed to be representative of these categories. Instead, estimates of the small samples in this survey provide indications to be discussed. Based on the literature, the nine categories can further described as follows:

Category 1: Highly commercialized cages. The farms in this category are mainly in Lake Victoria. This category is growing rapidly and therefore creating opportunities for the growth of other value chain actors. Siaya County has the most cages in Lake Victoria, and it is estimated that about 43 enterprises operate 4,000 cages with over 3 million tilapia fingerlings. The estimated value of tilapia from these cages is about USD12 million, at a production rate of 12 million kg of fish per eight-month production cycle (Obwanga *et al.*, 2018; Opiyo *et al.*, 2018; Njiru *et al.*, 2018). Tilapia is cultured at a very high stocking density of 359–560 fish/m^3 (mostly in 2m^3 cages, which are cheap and easy to install in shallow areas). This is beyond the recommended stocking density of about 50–100 fish/m^3. The highest production in Lake Victoria is recorded in Siaya County. Good quality fingerlings and feed remain the biggest challenge to this category. The cost of fingerlings is about USD0.05–0.10 for 20g and 50g fingerlings respectively, while smaller tilapia fingerlings weighing about 1–5g cost USD0.03 each.

Categories 2 and 3: Medium and low commercialized cages are installed in earthen ponds, community-owned dams, water pans or reservoir dams, as well as in the main water bodies (Ngugi and Manyala, 2009). Such cages may be owned by cooperatives or self-help groups (youth groups and women groups) and have been common in the central parts and north-eastern parts of the Kenya. The stocking density is similar to that described above in Category 1, although it tends to be higher in Category 2, with the aim of maximising profits. In Category 3, the cage sizes are smaller and the building material may be cheaper. The choice of farming type in Category 3 may be premised on the ease of managing fish cultured in cages compared to in ponds.

Category 4: Highly commercialized ponds. In this category, stocking density is 3 fish/m^2, which achieves yields of 1 kg/m^2 [5]. Rarely, stocking densities may be 6 juvenile fish/m^2 in ponds, resulting in yields of 3 kg/m^2 (Opiyo *et al.*, 2018). The pond surface area can reach up to 4,000-80,000 m^2, with enough space for more than 13 ponds.

Categories 5 and 6: Medium and low commercialized ponds. This category of fish farming uses a mixture of organic and inorganic fertilisers, and farmers supplement this with commercial feeds if they can afford it. However, if they cannot, farmers will use homemade feeds, pig pellets or poultry feed (growers mash and layers mash) to feed fish which has negative effects (see comments about this category in the section on external environmental/ climate enabling factors). In *Category 6,* farmers use their own labour, and a large percentage of the fish produced is consumed by the household, while the rest is sold at the farm gates either to neighbours or other customers (Obwanga and Lewo, 2017; Opiyo *et al.*, 2018). In this category, fish farming is a diversification option that often leads to low input and low output and is therefore characterised by below optimal performance, even losses (Farm Africa, 2018). In the past, this category was the focus of support from GoK and other NGO programmes that pushed for fish farming mainly for poverty alleviation and food security.

Category 7: Highly commercialized tanks. Farms in this category normally have indoors set-ups or are under greenhouses, ensuring that production is not affected by the seasons and can run for the whole year (Opiyo *et al.*, 2018). These systems produce tilapia and catfish (either in the form of hatcheries or grow-out farms) with a food fish production of 200 tons/ha/yr from a stocking density of 5–20 fish/m^3 (ibid.). Two notable farms that use this system are Kamuthanga and the Roost, developed through collaborative efforts with Dutch organisation Larive (Farm Africa, 2018). There is low adoption of this system due to the high cost of initial capital investment in tanks and greenhouses, as well as the cost of electricity required to run the system. This category works well with RAS, which is also usually expensive to set up and requires high technical expertise to maintain. In some cases, the set-up involves flow-through systems where there is plenty of water. High-quality feed and seed are required for profits to

[5] In the literature stocking density is often explained in m^2 for ponds. Note that in the household survey conducted in this study we have used m^3 to make it comparable to the other categories cae and tanks (e.g. Table 2).

be made. Key challenges facing this category include quantity and quality of feed and seed, scarcity in expertise for designing and managing RAS and keeping production costs low so as to compete with other production systems (Farm Africa, 2018; Koge *et al.*, 2018).

Categories 8 and 9: Medium and low commercialized tanks. The tanks in these two categories are smaller, and the set-up is in the backyard of urban or peri-urban spaces. Water storage/harvesting plastic tanks (instead of concrete tanks) are commonly used for this endeavour. The stocking density may not follow the guidelines. Such installations may also be used for small-scale production of fingerlings for sale to other farmers or for use in earthen ponds. In *Category 9* the farming is based on maximising very small spaces to produce fish for domestic use and selling any surplus to neighbours. Fingerlings are sometimes produced in rural set-ups either for stocking of grow-out ponds or sale to fellow farmers.

Household characteristics. Outcomes of the household survey in terms of core farm characteristics are listed for each commercialization category and production system in Table 2. For the cage and pond farmers, household sizes are smaller, farmers are younger and more highly educated and the areas used for the fish farms are larger as the level of commercialization increases. Large production volumes are seen in medium commercialized cage farms, and years of experience in fish farming do not necessarily lead to higher levels of commercialization. Variability within each category may be high, which is also confirmed by the standard deviations estimated for each value. The large variability, especially for the tank farmers, can be due to the small sample sizes. Figure 8 below shows the variability in land size and volumes of production systems in more detail.

Table 2: Overview of core farm characteristics by commercialization category

Production system	Characteristics	Commercialization level					
		High	SD	Medium	SD	Low	SD
Cages (81)	Average household size (people)	6.5	6.5	7.1	3.6	8.7	4.3
	Average age of farmer (years)	42.1	11.5	44.4	9.3	45.8	9.0
	Average land sizes (acres)	2.5	1.3	1.86	1.2	1.75	1.0
	Average level of education (years)	7.3	3.8	7.0	3.8	7.0	3.5
	Average volume of production system (m^3)	1,846	5,583	1,371	4,070	358	452
	Average experience in fish farming (years)	1.8	0.9	3.2	3.2	2.2	0.9
Ponds (199)	Average household size (people)	4.3	2.2	5	2.4	5.5	3.4
	Average age of farmer (years)	55.5	13.5	55.1	13.6	58.3	13.6
	Average level of education (years)	9.1	1.2	8.5	1.3	8.1	1.3
	Average land sizes (acres)	5	9.6	4.8	8.1	4.3	8.5
	Average volume of production system (m^3)	4,616	9,578	4,359	8,300	2,317	4,204
	Average experience in fish farming (years)	7.15	5.6	7.2	4.8	9.4	8.1
Tanks (20)	Average household size (people)	5.1	2.6	5	2	5.7	3.8
	Average age of farmer (years)	46.6	10.7	48.5	13.2	41.7	17.6
	Average level of education (years)	10.4	0.7	11.0	0.5	11.0	0.2
	Average land sizes (acres)	37	79	5	4	42	67
	Average volume of production system (m^3)	7,092	6,423	2,002	4,438	16,803	14,458
	Average experience in fish farming (years)	10.4	11.8	9.9	4.7	5	3

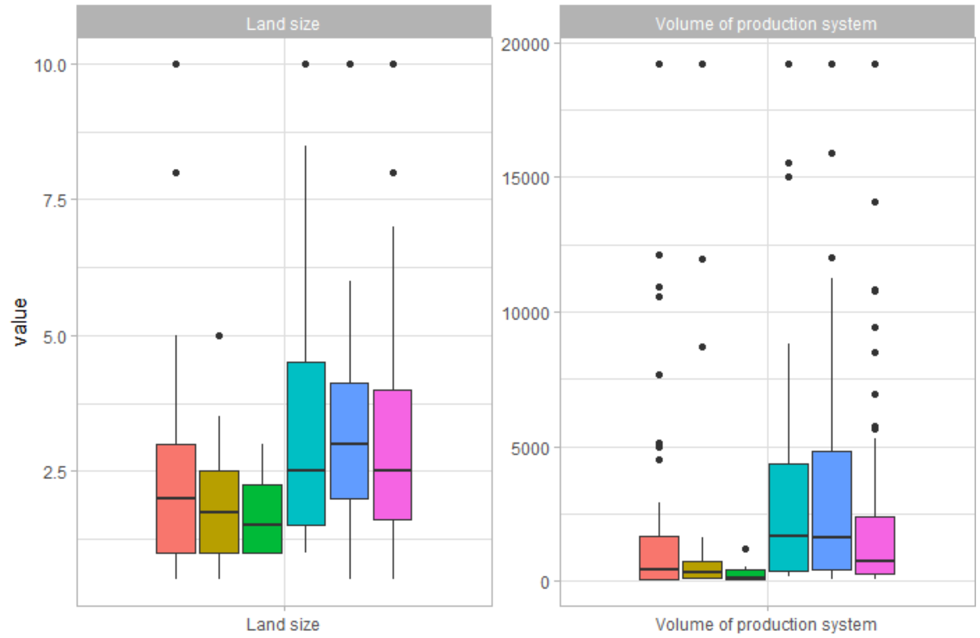


Figure 8: Variability of land size and production volumes within cage and pond categories (example with removal of 5% of outliers)

Share of fish species produced per category. Figure 9 shows the average species produced for each category. Tilapia is the most dominant species produced, because it currently fits consumer preferences the most. Four categories produce only tilapia (all cage farms and the tank category with the low level of commercialization). The low commercialized ponds also produce mostly tilapia (86%), supplemented by catfish production. Of the other pond farmers, 67% produce tilapia, supplemented by mostly catfish production. The medium and highly commercialized tank producers also produce ornamental fish and trout.

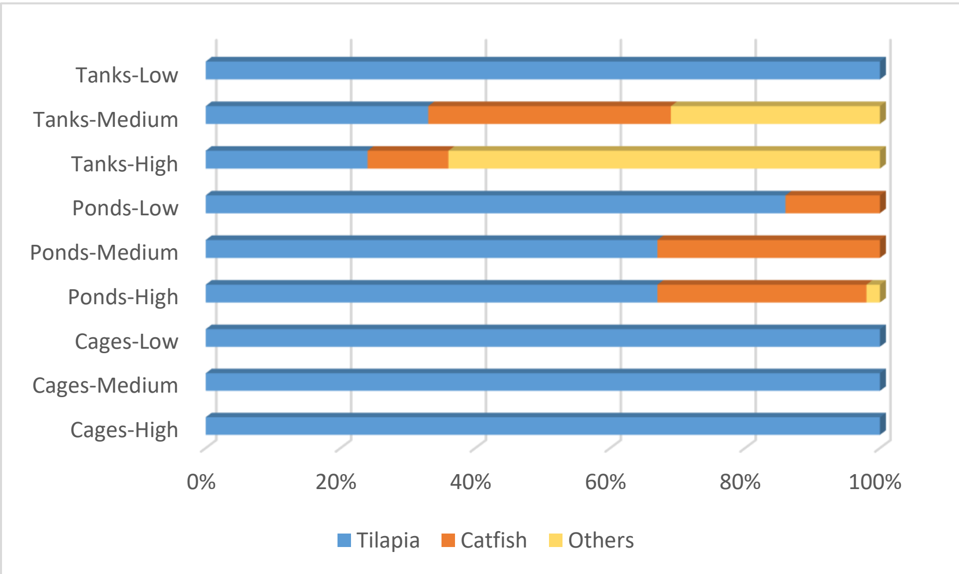


Figure 9: Average share of fish species produced per category

4.2 Aquaculture value chain production (fish) and inputs (fingerlings/pellets/water)

This section provides estimates of aquaculture value chain production and inputs for each commercialization category. The variables investigated are gross margin, production potential, stocking share of total capacity, production of fingerlings, use of pellets and use of water resources.

Gross margin. The average gross margin is estimated by subtracting average total variable costs from the average gross sales for each category (Figure 10). Although this shows that the gross margin is very different across the categories, all categories are profitable.

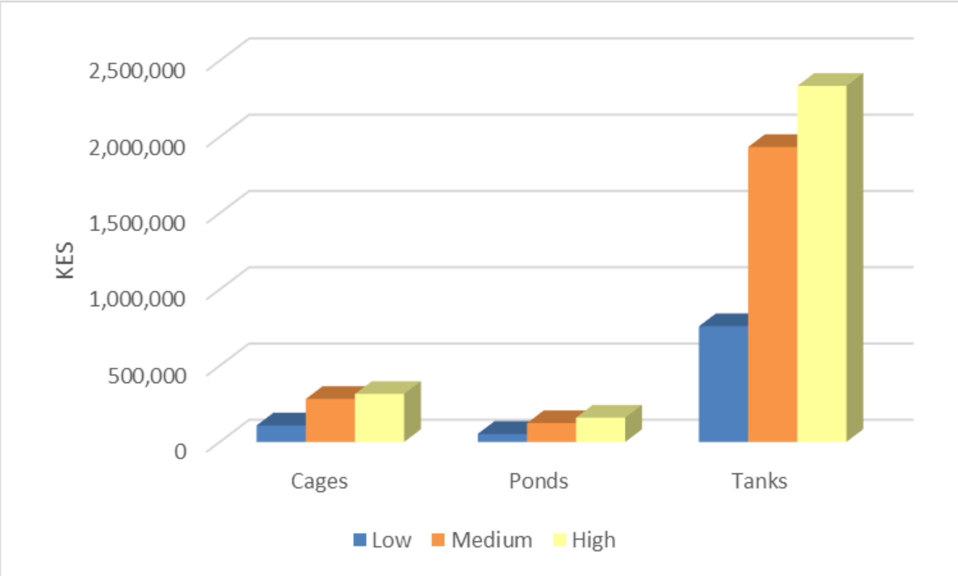


Figure 10: Gross margin across the nine categories

Production potentials. Table 3 provides an overview of more specific production values across the nine commercialization categories. It shows that the high commercialization categories for both cages and ponds have very similar incomes and variable costs per year, but the average value of the production system – that is, the price the farmer could receive from its sale – is higher for ponds than cages. In contrary, the medium commercialized cages have a very high value of the cage production systems; this can be explained by the variability already observed within the categories (see Figure 8). Table 3 illustrates that the tank production systems have much higher incomes and variable costs than the other production systems, and are therefore operating at a different scale. Notably, leasing costs are variable costs, and the value of the production system is included in the fixed costs (see Appendix 1 for more details about the variable costs). Cage farmers may pay the Beach Management Unit at Lake Victoria and then continue producing, while for instance the pond system depends on the value of land which will vary sometimes very much with the region.

Table 3: Overview of production values (KES) per production system and commercialization level

Production system	Production values (KES/Year)	Commercialization level		
		High	*Medium*	*Low*
	Average income coverage from aquaculture	540,859	300,943	85,011
	Average value of production system	372,294	646,583	173,333

Cages	Variable costs (TOTAL)	173,066	94,217	25,081
	Hired labour costs	*79,723*	*44,890*	*1,091*
	Floating pellets costs	*83,723*	*36,264*	*14,090*
	Maintenance costs	*9,620*	*13,063*	*9,900*
	Water costs	*0*	*0*	*0*
Ponds	Average income coverage from aquaculture	534,508	412,964	157,126
	Average value of production system	467,000	402,507	314,498
	Variable costs (TOTAL)	167,335	57,082	22,361
	Hired labour costs	*72,460*	*10,730*	*4,224*
	Floating pellets costs	*75,401*	*35,877*	*10,550*
	Maintenance costs	*16,045*	*9,149*	*7,587*
	Water costs	*3,429*	*1,326*	*0*
Tanks	Average income coverage from aquaculture	27,100,000	7,580,000	10,000
	Average value of production system	3,150,000	1,150,000	970,000
	Variable costs (TOTAL)	1,912,379	1,530,253	207,094
	Hired labour costs	*417,600*	*431,836*	*93,854*
	Floating pellets costs	*1,300,000*	*736,142*	*22,240*
	Maintenance costs	*145,579*	*301,525*	*85,000*
	Water costs	*49,200*	*60,750*	*6,000*

Stocking share of total capacity. It is of interest to know whether increasing production would require additional investment in the production system. The stocking share can indicate whether the farm has potential to increase production within the present system. If the stocking share is high, the need for investment is more urgent. The differences between present and maximal stocking capacities for tilapia across categories are illustrated in Figure 11. It appears that all pond categories have the largest potential to increase stocking capacity within the existing systems.

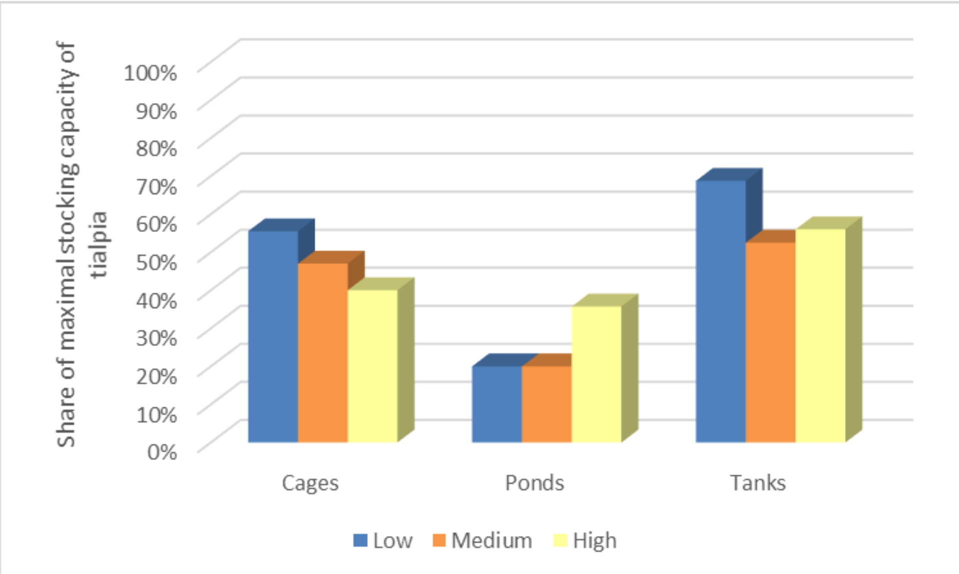
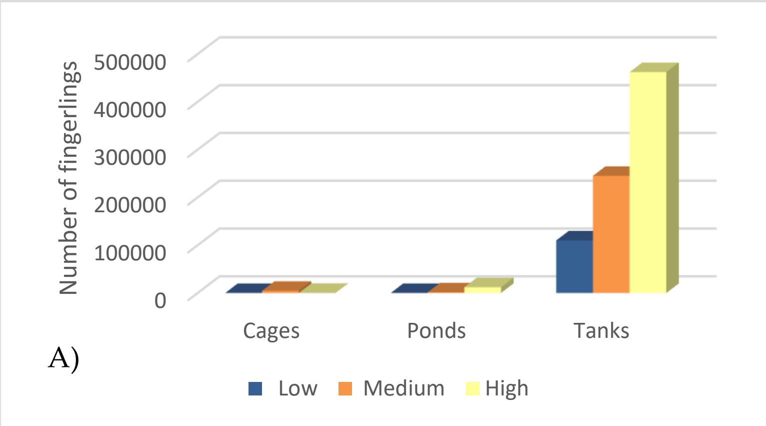


Figure 11: Share of used per maximal stocking capacity of tilapia in existing systems across categories

The following section provides estimates of aquaculture inputs (fingerlings and pellets) for each category.

Production of fingerlings. Fingerling production is provided in number of pieces (not weight). Figure 12 shows that the number of fingerlings produced on the farms increases as the commercialization level of ponds and tanks increases. For cages, the medium commercialized farmers produce the most. Because of the scale differences, two figures are provided: one with and one without the tanks (A, B).



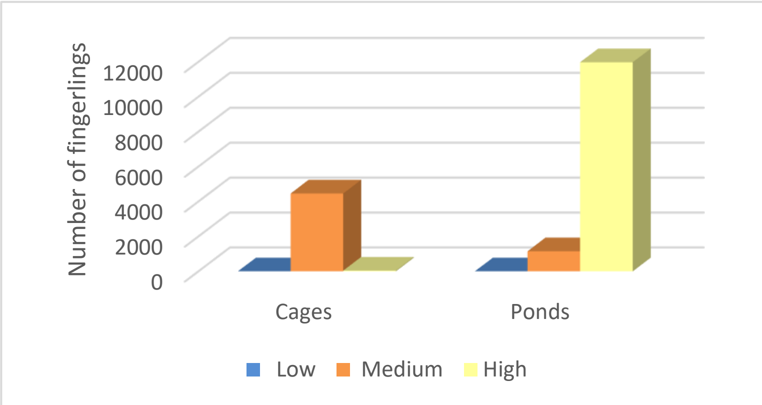


Figure 12: On-farm production of fingerlings (number of pieces, not weights) across the nine commercialization categories: A) including tanks, and B) for cages and ponds only

Use of pellets. Figure 13 shows the mean costs of floating pellets. The interviewees also reported on costs of sinking pellets, which were observed in only two categories: medium commercialized ponds and highly commercialized tanks. In the latter category, the one responder provided very high costs (about KES12M), which is not included in the figure due to the large-scale differences and few responses. As shown in Figure 13, the costs for pellets increase as commercialization increases within each category, although average costs are a lot higher for the two highest commercialized categories of tanks.

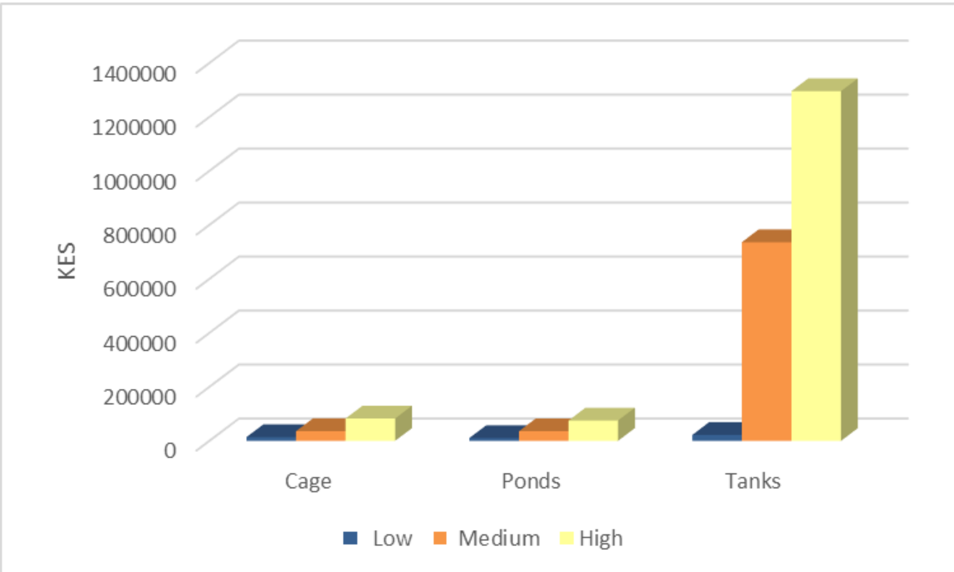


Figure 13: Share of mean costs floating pellets per category (KES) across the nine commercialization categories

Use of water sources. Figure 14 shows that pond farmers use a highly diverse variety of water sources, including springs, streams and other water sources, while the cage farmers use rivers/lakes as the water source (notably, a small share of the most commercialized cage farmers also make use of water pan/reservoir. Most pond and tank categories' use water from a number of different sources, while the low commercialized tank farmers use water from either boreholes or rivers/lakes.

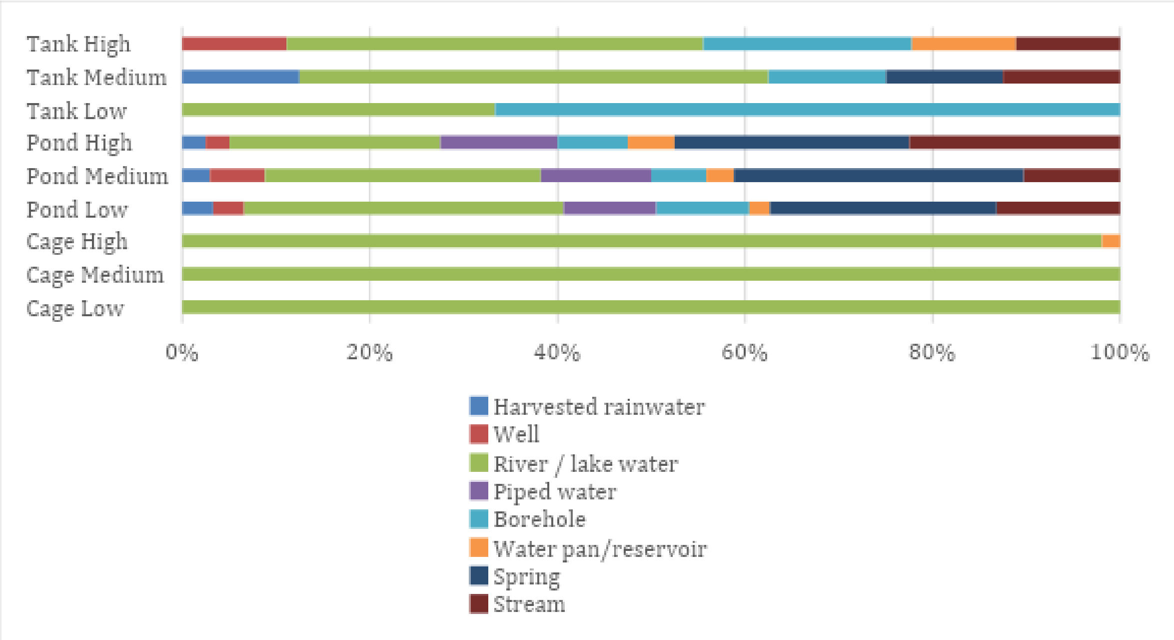


Figure 14: Use of water sources across the nine commercialization categories

4.3 Aquaculture value chains after production: sales, losses, transport, consumption and level of risk perception

This section provides estimates of sales and losses, levels of access to own transport, consumption patterns and levels of risk perception for each category. The average amounts sold to different market outlets for each category are listed in Figure 15, and the prices per product per outlet category are provided in Table 4. The average consumption of own produce is shown in Figure 16. The pre- and post-harvest losses are shown in Figure 17, and the access to own transport is shown in Figure 18.

Average share of produce sold to different market outlets. The average market outlets receiving fish produced across the nine categories are provided in Figure 15. A relatively large market outlet for all categories is sale to individuals at the farm gate or at a market. Retailers purchase the largest share of cage-farmed fish. For tank farmers, the market outlets differ in each category, as institutions are an important group to the highly and medium commercialized categories. Note that institutions represent a targeted market; the main consideration for them is stability of supply. They buy a fixed volume of fish at a good price but do not pay on delivery and these sales are prone to payment delay. Retail is also important to the highly commercialized tanks category, with some produce also sold to brokers and wholesale. For the low commercialized tank farmers, the wholesale and brokers together form half of their market outlets.

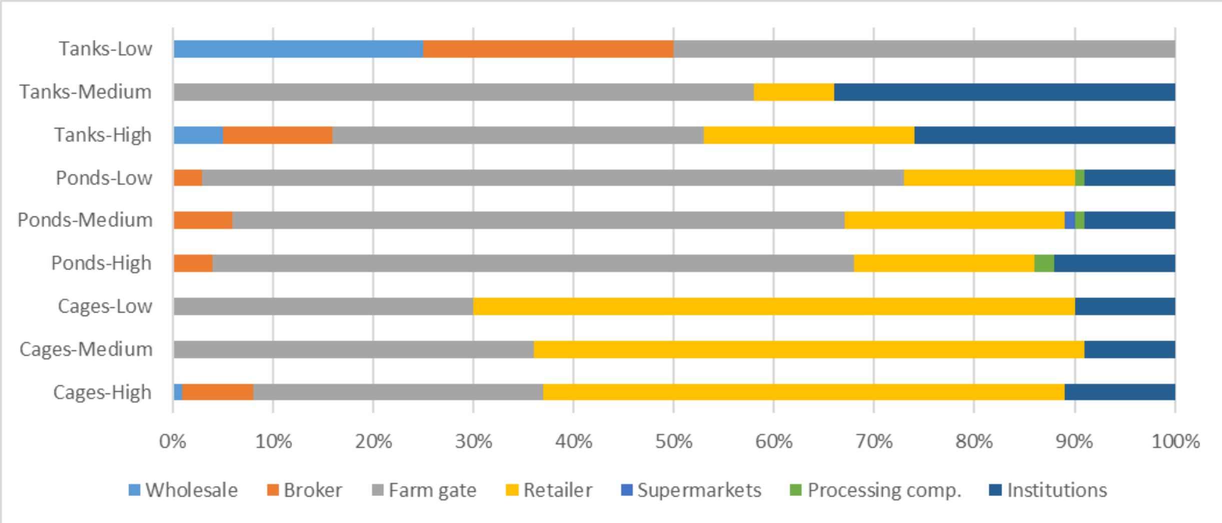


Figure 15: Share of aquaculture output sold to market outlets: wholesale, brokers, individual consumers, retailers, supermarkets, processing companies and institutions.

Prices per product. It is of interest to see what prices the different market outlet categories pay for fish from each of the nine categories. The diversity of market outlets and average prices for each species are listed in Table 4 for each category. There is more diversity of market outlets for pond farmers than for cage and tank farmers. The price of tilapia varies from KES188 to KES561 per kilogram. The price of catfish also varies a lot and was reported in the range of KES150–450/kg. The price of trout varies the most and is relatively high, in the range KES500–1375/kg. The price depends on the targeted market outlet and is set by the buyer of the products. Comparing, for instance, prices for tilapia sold to retailers or individual consumers across highly commercialized categories, the highest prices are paid to the pond farmers, followed by the cage farmers, and a relatively low price per kilogram is paid to the tank farmers. In contrast, the prices for trout produced by the tank farmers are high. That is, they can sell small amounts of stock without many consequences. But in other systems, due to the high intensity, there is a high cost of maintaining large volumes of mature fish; hence, farmers tend to dispose of them at lower prices. The role of brokers in the highly commercialized systems, particularly cages and ponds, cannot be ignored. Brokers could be willing to pay relatively better prices to farmers when relatively large volumes are traded in highly commercialized systems. Also, pond farmers may sell at retail to the final consumer, while in other systems farmers sell at wholesale, and therefore for a different price.

Table 4: Average prices per species, market outlets and commercialization categories

	Average prices (KES/kg)		
	Cages	**Ponds**	**Tanks**
High	Tilapia wholesalers (320) Tilapia retailers (322) Tilapia individuals (307) Tilapia institutions (450) Tilapia brokers (407)	Tilapia retailers (344) Tilapia individuals (372) Tilapia institutions (411) Tilapia brokers (400) Catfish retailers (233) Catfish institutions (440) Catfish individuals (362) Catfish processors (250) Catfish brokers (300)	Tilapia retailers (188) Tilapia brokers (350) Tilapia individuals (213) Catfish individuals (150) Trout retailers (1,000) Trout individuals (1,125) Trout institutions (1,375)
Medium	Tilapia retailers (329) Tilapia individuals (327) Tilapia institutions (475)	Tilapia retailers (331) Tilapia processors (200) Tilapia individuals (364)	Tilapia retailers (600) Tilapia individuals (520) Tilapia institutions (425)

		Tilapia institutions (518) Tilapia brokers (300) Catfish retailers (328) Catfish institutions (361) Catfish individuals (275)	Catfish individuals (450) Catfish institutions (425) Trout individuals (1,000) Trout institutions (1,000)
Low	Tilapia retailers (292) Tilapia individuals (470) Tilapia institutions (480)	Tilapia retailers (314) Tilapia processors (250) Tilapia individuals (346) Tilapia institutions (561) Tilapia brokers (243) Catfish retailers (200) Catfish processor (300) Catfish individuals (297)	Tilapia wholesalers (250) Tilapia individuals (300) Trout individuals (500)

Share of meals consumed of own-produced fish. This section provides estimates of the share of fish meals consumed that were produced by the farmer, for each category, in Figure 16. This is used as an indicator because if farmers consume the fish they produce, they forgo income. Consumption of own-produced fish can be a variable indicating food security. For every category, at least some of the produced fish is consumed by people on the fish farm. This is more often the case among pond farmers, and least often for the highest commercialization levels of all production systems. For the medium commercialized tank farmers, a relatively large share of their fish meals are fish they have produced themselves.

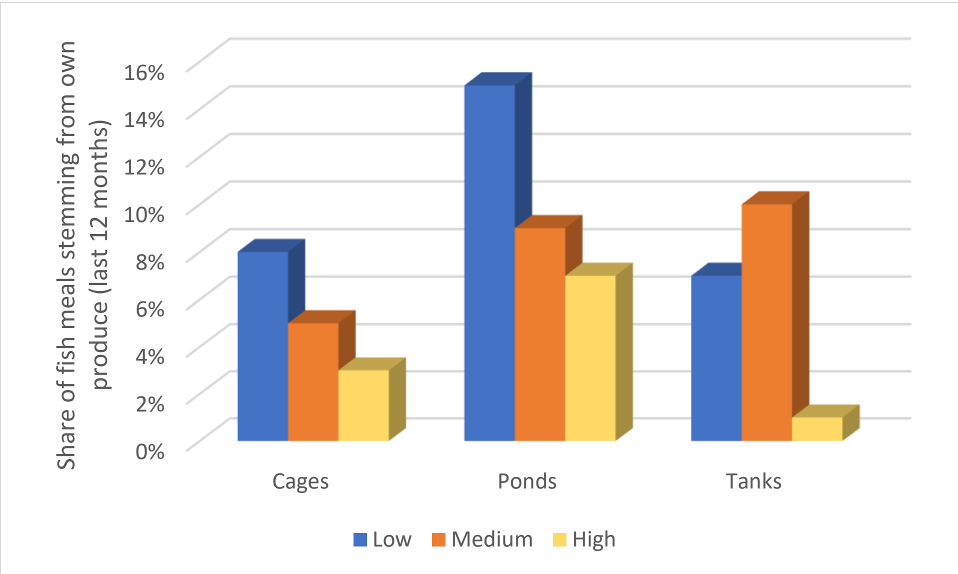


Figure 16: Average share of fish meals consumed from own-produced fish as share of total fish consumed in the last 12 months

Pre- and post-harvest losses. What is not sold to market outlets is lost, either before or after harvest. Figure 17 show pre-and post-harvest losses for each fish farm category. The pre-harvest losses as a share of production for the medium and low commercialization levels of tank farms are extremely high (more than 33–35%), which is a result of overcrowding of fish, as well as poor management practices and understanding of the technology. Tanks need a constant supply of fresh water due to overcrowding of fish; if the supply runs low or there is a slight delay in replacing the water, fish die and this is reported as losses. In the highly commercialized tank farming, the losses are very low. Pre-harvest losses are also relatively high for the low commercialization levels of both cages and ponds. For medium commercialized cage farming and highly commercialized pond farming, the post-harvest losses are higher than the pre-harvest losses.

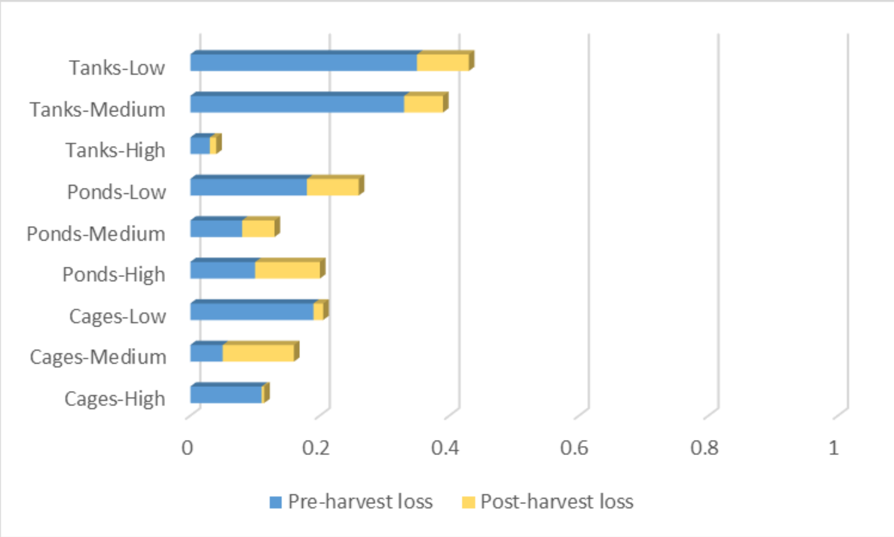


Figure 17: Average pre- and post-harvest losses (as share of production) across the nine commercialization categories.

Access to own transport. Figure 18 shows the percentage of farmers across all the production systems who have access to their own transport. This indicates the extent to which they can transport fish effectively to market outlets if they are not selling at the farm gate or at nearby markets. Better access to own transport is shown for higher commercialization levels in both the cage and pond categories. The pond owners have better access to their own transport than cage farmers: 50–70% across the three levels of commercialization. It is striking that the cage farmers have such low access overall, given that farmers in this category are located further away from some of their market outlets. The tank farmers have relatively better access to their own transport, but this is the opposite trend to that of the cage and pond farmers; that is, the lowest commercialized tank farmers have the most access. This is because customers go to the tank farms to purchase fish. Cages are more intensive, and mostly fish are not harvested until the market has been secured and the fish purchased on the shores of the lake. Thus, it is unlikely that cage farmers need their own transport to sell their fish.

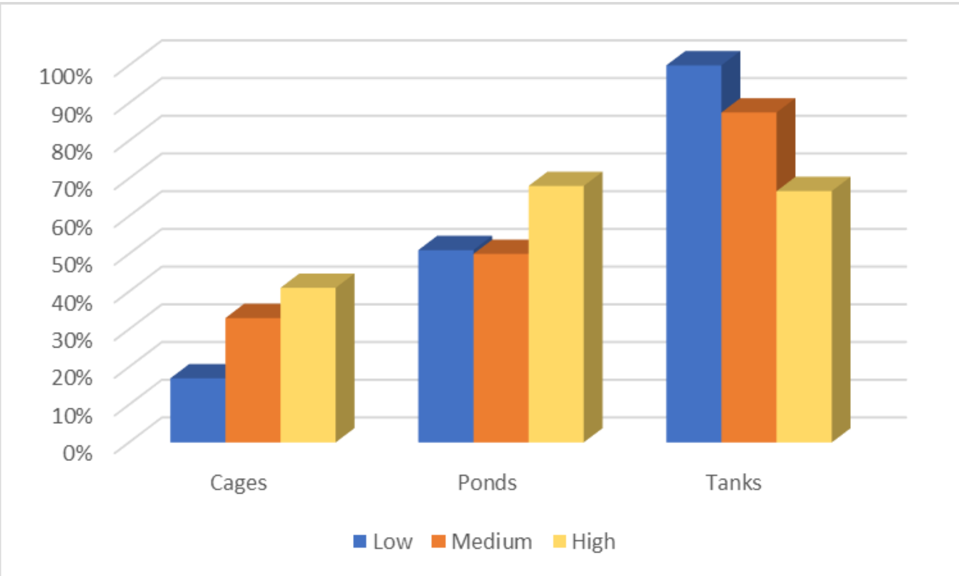


Figure 18: Average percentage of farmers in each category having access to their own transport across the nine categories

Level of risk orientation. Often linked with market orientation is the willingness to take risks. The survey asked questions about risks, and the results show that all tank owner categories take more risks than farmers in the cage and pond categories (Figure 19). The low commercialized cage owners are extremely risk-averse, followed by the farmers in all pond categories. These results do not confirm the expected trend shown in Table 1, that risk orientation correlates with commercialization level.

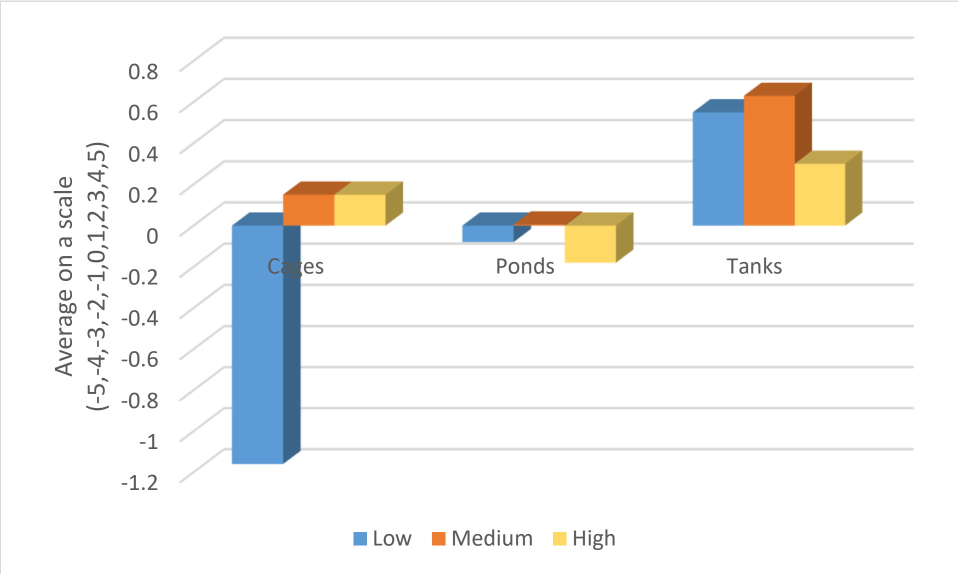


Figure 19: Average self-perception about taking risks across the nine commercialization categories

5 Investment in the aquaculture sector in Kenya

Investment in aquaculture is seen as an important enabling factor for the growth of the sector across the nine commercialization categories. This chapter describes results from the household survey of the estimates of investments made in each category and the source of funds. Thereafter, some insights about investments across the nine categories are explained more thoroughly, based on a literature review.

Figure 20 shows that the largest shares of investments are made by farmers themselves, and that most also received some external kind of support. Both the medium and highly commercialized tank farmers received a subsidy, and the pond farmers received support in terms of having the installations for free ('Free (partly)'). Some tank producers were initially given the tank system free, which was a form of assistance from the government and NGOs. For the low commercialized ponds, a number of farmers took the initiative to invest in themselves, and others took loans to invest. The cage farmers took out the highest loans. Participation in ESP took many formats: some received a full package (dug ponds, liners, fingerlings, feed and other inputs), while others received partial support. Only one category, the low commercialized tank farmers, received no external support.

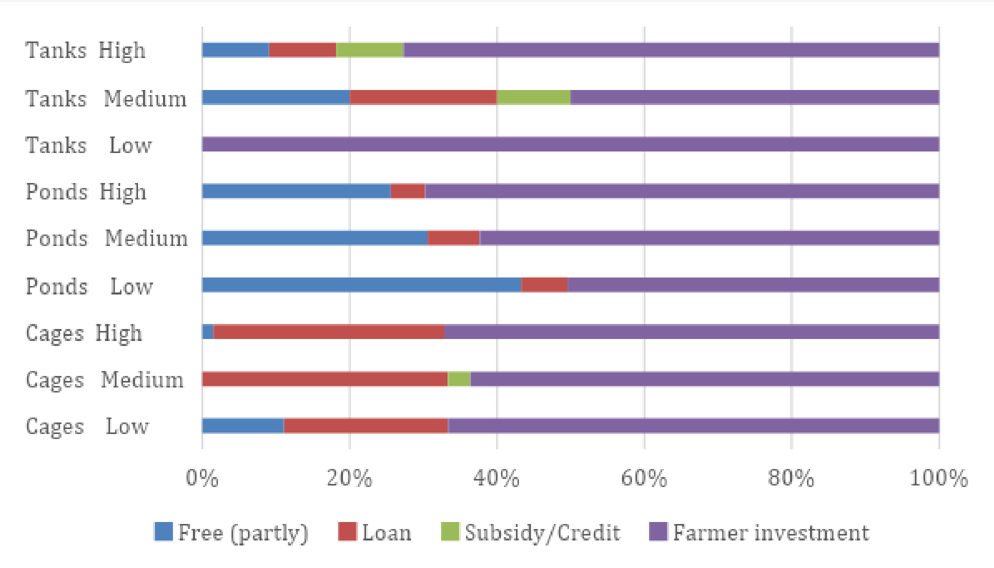


Figure 20: Origin of investments across the nine commercialization categories

Category 1: Highly commercialized cage farmers depend on high investment levels, and lack of or insufficient financing and/or insurance opportunities makes aquaculture a highly risky business venture. However, investment has been successful in several cases. One example is Winnie's Farm at Anyanga Beach on Lake Victoria, which started with 60 cages in 2013 and, with intensive investment, currently owns 550 cages and collaborates with around 100 farmers (Obwanga *et al.*, 2018; Opiyo *et al.*, 2018). This segment demands high-quality floating feed, which has spurred investment into and growth of the local fish feed industry (e.g. Sigma Ltd, Unga Feeds Ltd, Lenalia Feeds Ltd). To get sufficient high-quality feed, some entrepreneurs have invested in imports of fish feed from the Netherlands, Norway, Denmark, Israel, Mauritius, Uganda and Ghana (Opiyo *et al.*, 2018). Cage construction material is also imported from abroad, and prices are high. To reduce prices, importers of cage construction material are lobbying for reduced taxes or zero rating of materials imported for use in aquaculture. In *Category 2: Medium commercialized cages*, investment is lower. The nature of cage culture demands high investment in inputs and, especially when using public facilities and when farming in groups, use of expensive inputs such as feed and cage construction material is reduced. In C*ategory 3: Low commercialized cages*, investments are even lower. The cage construction material used is cheaper and may be sourced locally.

For *Category 4: Highly commercialized ponds,* investment in high-quality inputs results in better profit margins. Investment in this category seems to be driven by proximity to urban markets (which also includes proximity to traditional fish-eating communities) as well as to suitable landscapes that provide suitability for large farm sizes (Farm Africa, 2019). In *Category 5: Medium commercialized ponds*, insufficient investment is observed for inputs. These farmers use a mix of high and low quality inputs and are reluctant to spend more on the equipment necessary to improve their production (Farm Africa, 2019). In *Category 6: Low commercialized ponds*, investment in farms is not necessarily providing return. These farmers do not use quality inputs for their enterprises, and revenues do not cover their costs; hence, they incur losses. A major source of losses in this category is due to the use of homemade feeds. As a result, investment in this category is low (Farm Africa, 2016; KMAP, 2017).

In *Category 7: Highly commercialized tanks,* the number of farmers who have invested in tanks is low due to the high cost of initial capital investment in tanks and/or greenhouse construction, as well as the high cost of the electricity required for running the RAS (Opiyo *et al.*, 2018). In addition to maximising profits, proximity to markets influences the set-up of such an enterprise, as seen in Nigeria in the Fish Farming Estates model (FFE) (Obwanga *et al.*, 2018). In Kenya, RAS for Nile tilapia and the African catfish are set up in proximity to the peri-urban areas of Nairobi, Nyeri, Meru, Kisumu, Machakos, Kilifi, Homa Bay, Kakamega and Busia (Opiyo *et al.*, 2018). In *Categories 8 and 9: Medium and low commercialized tanks*, money for investment is sourced from personal savings or loans secured to support other enterprises. In *Category 9*, minimal investment is made. If the farmer considers that plastic tanks are too expensive, square or rectangular wooden crates (1 m^3 dimensions) with liners are used for stocking the fish. Use of floating feeds is minimal, and sustainability of such an investment is normally very low

6 Institutional governance as an enabling factor to the aquaculture sector

Institutional governance is illustrated as supporting activity in the aquaculture value chain in the analytical aquaculture food system framework (Figure 1). This section details the percentage of farmers who took part in the ESP (Figure 21), farmers who accessed extension services one year before the survey was conducted in 2018 (Figure 22) and farmers' trust in government (Figure 23). While it is of interest to see whether the ESP has contributed to increasing commercialization, and if so for whom, level of trust in the government is often perceived as a major factor of social capital and necessary for business development (Soma *et al*., 2015). These outcomes of the household survey are followed by some insights based on the literature.

Government support. Between 2010 and 2014, the ESP (see Introduction and section 3.1) has been one of the largest government initiatives aimed at boosting the aquaculture sector based on subsidies and other types of support, such as capacity-building. The household survey results show that all pond categories and the medium commercialized tanks have benefited the most from the ESP (Figure 21). Of the cage farmers, only a few in the middle category received some support, and one or two in the high commercialized category. The support through ESP does not necessarily correlate with the level of commercialization.

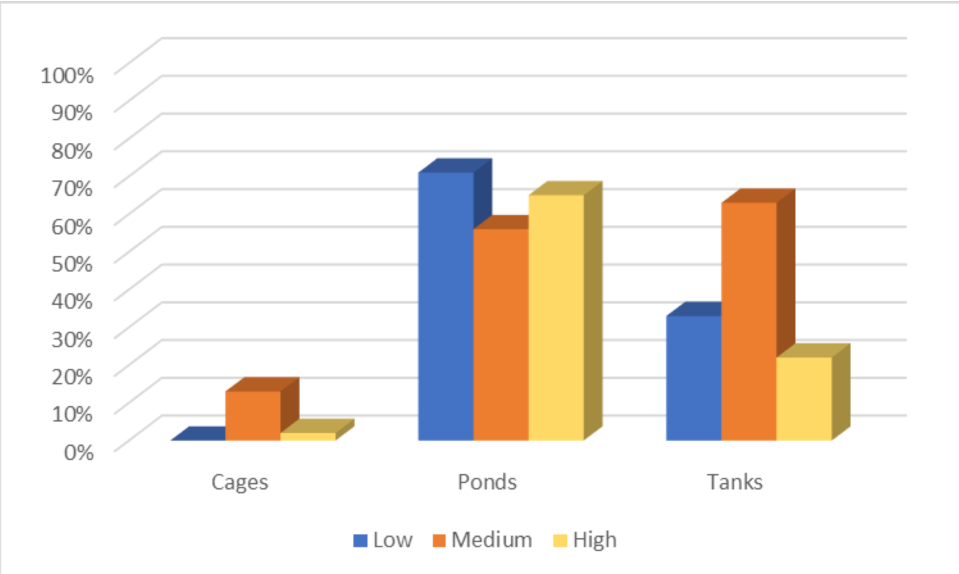


Figure 21: Average share of farmers who took part in the Economy Stimulus Programme across the nine commercialization categories

In Kenya, the government provides support in the form of extension services. Figure 22 shows the number of times farmers in each category were in contact with these services. While highly commercialized cages and medium commercialized tanks had an average of 12 contact events per year, the other cage categories and the highly commercialized tanks had no contact at all. The pond categories had 4–10 contact events per year on average.

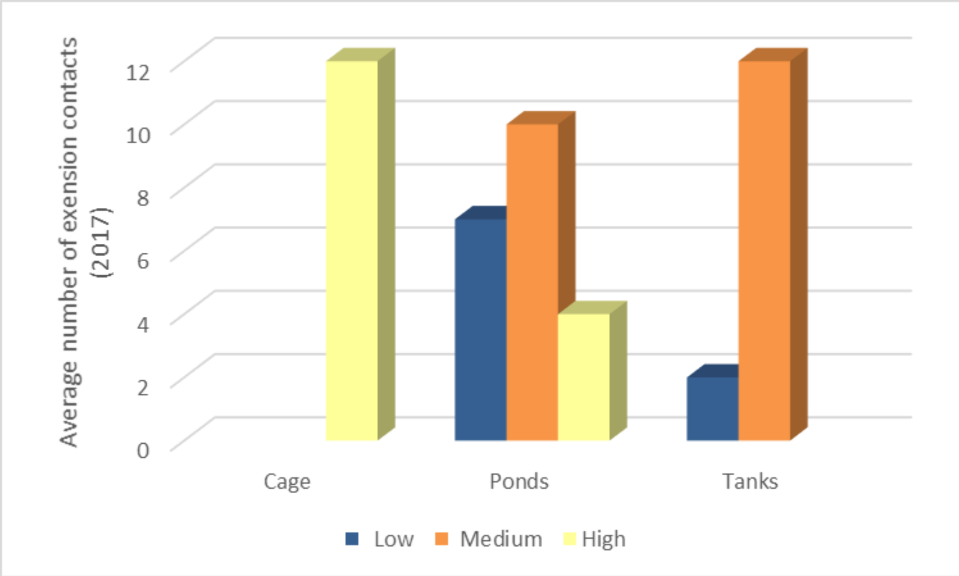


Figure 22: Average number of times the farmers in each category were in contact with extension services in 2017

Since 2010 through the ESP, government and aquaculture farms have worked together to set up this sector. A high trust level aids further development. Figure 23 shows the trust levels across the nine commercialization categories. Relatively low levels of trust in the government exist for the cage farmers with high levels of commercialization and for the tank farmers with low level of commercialization. The highest trust levels are found among the cage farmers at medium commercialization level, followed by the highly commercialized tank farmers.

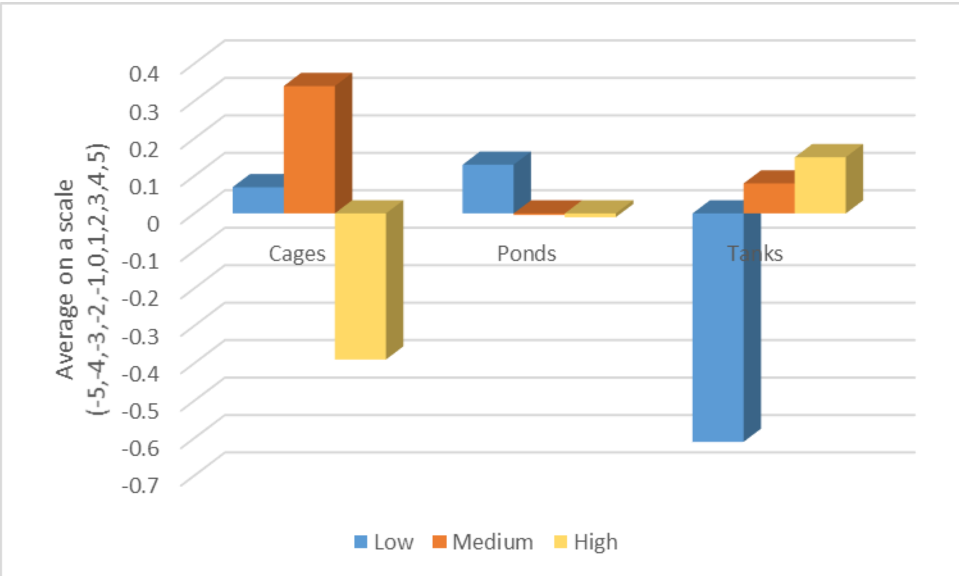


Figure 23: Average trust (distrust) in government across the nine commercialization categories

The GoK has pushed the growth of *Category 1: Highly commercialized cages* from the outset. Intensive cage culture was developed after the successful cage trials carried out by the Kenya Marine and Fisheries Research Institute (KMFRI) in collaboration with Dunga Beach Cooperative Society with support from the Association for Strengthening Agriculture Research in East and Central Africa. KMFRI has written manuals and brochures on best culture and management practices for cage culture, but there is still need for enhanced collaborative tailor-made training by the GoK training and research institutions. Weaknesses in management and regulation of cage culture can be blamed on insufficient funding and human resources, uncoordinated policies and regulations, confusion over management and regulation after devolution, and the fact that this category is growing faster than the governance mechanisms. This threatens the sustainability of farming in Lake Victoria, may lead to an environmental disaster and to conflict with other resource users (Njiru *et al.*, 2018; Obwanga *et al.*, 2018). An effective policy framework and mapping of the lake based on resource use will result in better management and regulation of cages and reduce conflict among users (Njiru *et al.*, 2018). Moreover, despite the GoK offering training on fish handling, safety and hygiene as well as enforcing the Fisheries Regulation (Fisheries Act Cap 378), it seems that the training is not sufficient. Technology in fish handling and processing is either low or rudimentary, and there is need for GoK training in this area due to the potential of this category to grow and increase production volumes (Farm Africa, 2016). In *Categories 2 and 3: Medium and low commercialized cages,* farming in community-owned resources such as dams and water pans comes with immense challenges. Use of these water bodies by individuals for fish farming may not be an endeavour the whole community is interested in. The fish farmers may find the steps and processes required to acquire permits demanding. However, it is easier for youth and women's groups to get permits due to the perception that they are vulnerable and need to be supported.

Category 4: Highly commercialized ponds has grown following the push for aquaculture to become commercial. Having taken the lead, the extension and other related governance activities have had to catch up: there is need to update the extension content and delivery model, given that it is mostly based on semi-intensive fish farming (which may be irrelevant to this category). This category therefore provides opportunities for enhancing extension and creating lessons for future governance in the sector.

Categories 5 and 6: Medium and low commercialized ponds have been the focus of GoK initiatives to ensure increased fish consumption, poverty alleviation and job creation among youth, and as such they receive extension services (Ngugi and Manyala, 2009; Obwanga and Lewo, 2017; Obwanga *et al.*, 2018). It is also common that in these categories fish farming is not a stand-alone activity by relies on other enterprises such as dairy and poultry farming for support. Fish farmers have found it easier to access the cooperative societies for dairy, for instance, to access services such as extension and financing.

Regulation and management of *Category 7: Highly commercialized tanks* is only loosely covered in policy frameworks and Acts, which means the management of effluent and water use, for example, is weak. *Categories 8 and 9: Medium and low commercialized tanks* are unregulated enterprises mostly carried out by youths (in groups or as individuals). These may be entrepreneurs who have just completed college or university or who are working or newly employed and may have secured a loan or are using personal savings. Access to extension and technical support is still scarce or non-existent. Current practice is ahead of the traditional aquaculture training manuals that have focused on small-scale pond farming of tilapia or catfish. Entry and exit from these categories are also not managed, hence control issues like effluent management become an issue in the peri-urban spaces, a challenge also noted in the Nigerian FFEs (Obwanga *et al.*, 2018).

7 The socioeconomic, inclusiveness, environmental and climate enabling factors

As stated in Figure 1, the aquaculture food system approach includes factors beyond the food system variables. Socioeconomic, inclusiveness, environmental and climate enabling factors are critically important and explanatory as food system outcomes, as well as for food security, food safety and nutrition outcomes. A literature review was conducted to explain how this works for the nine categories defined for the aquaculture sector in Kenya.

Socioeconomic and inclusiveness enabling factor. Dwindling wild fish catches, ready markets for farmed fish and the potential to create jobs for riparian communities have created the impetus for *Category 1: Highly commercialised cages* in Lake Victoria. Intensive cage farming has created employment opportunities, increased income and increased supply of protein (Njiru *et al.*, 2018). Supportive enabling factors that create great potential for marketing of fish from this category include already existing networks among fish traders, the take-up of mobile money technology among traders and general consumers, active participation from men and women in the fish trade as well as already established distribution channels from suppliers to consumers (Farm Africa, 2016). Other enabling factors are campaigns on the nutritional value of fish, a rising middle class with increased purchase power ready to spend on fresh fish, and the opportunity for access to the European market due to improved standards and quality (through the Standard and Markets Access Programme) (Farm Africa, 2016). Farming in *Categories 2 and 3: Medium and low commercialised cages* is driven by women and youth groups who maximise use of communal water pans/reservoirs or dams for fish farming. Fish farming in this category provides a diversification option in addition to tree nursery farming or irrigation of horticultural crops. However, use of public resources for fish farming, especially in areas that are not usually fish-eating, can create conflict in resource use.

Farming in *Category 4: Highly commercialised ponds* is supported by demand for fresh fish, the available opportunities in good quality feed manufacture and importation, available platforms for peer-to-peer farmer learning and the opportunity for men and women to both participate in farming (Farm Africa, 2018; Obwanga *et al.*, 2018; Opiyo *et al.*, 2018). The Aquacultural Association of Kenya, Aquaculture Roundtable and Commercial Aquaculture Society of Kenya (CASK) have provided platforms for farmers to lobby for better conditions in the industry. In *Categories 5 and 6: Medium and low commercialised ponds*, lack of robust management systems and business acumen among the farmers causes problems. The farmers have limited understanding of market dynamics and the economics of fish production, and they have low or no financial management capacity. This combination of lack of technical capacity and business acumen causes the category to become unattractive for investment (Farm Africa, 2018). *Category 6* is particularly characterised by slow adoption, low investment and poor uptake of knowledge (hence, incorrect siting of ponds, stocking density and feeding practice is common); farmers in this category may just rely on the environment to produce the fish (Farm Africa, 2018). Most farmers producing fish in this category are either retirees or elderly, which affects the sustainability of such enterprises.

Category 7: Highly commercialised tanks capitalises on proximity to markets, which are mostly in the urban or peri-urban areas. Due to high efficiency, only few employees are needed. *Category 8: Medium commercialised tanks* is driven by entrepreneurs who wish to maximise space and exploit the market in urban and peri-urban areas. Another aspect of growth in the aquaculture industry in this category is that demand for fingerlings drives establishment of makeshift hatcheries. Farmers in this group are also innovative and have seen opportunities in use of alternative animal protein (e.g. black soldier fly larvae) to manufacture homemade rations for fish feed. *Category 9: Low commercialised tanks* is driven by the need for cheap protein in urban spaces and the opportunity to exploit these spaces for enterprises such as fish farming. However, fish farming can also cause conflict with neighbours if effluent is not properly managed.

Environmental and climate enabling factors. The environmental and climate enabling factors are shown in Figure 1. Here, they are described in more detail. In *Category 1: Highly commercialised cages*, large unexploited zones exist in Lake Victoria, and other natural water bodies in Kenya have potential for cage culture. The fish are farmed in their natural environment, and the cages can be moved to other locations if needed. Limitations to the growth of this category are a) impacts of the production system on the environment, and b) impacts of the environment on the production system. Examples of the first limitation include pollution by waste feed and faecal material, spikes in diseases (due to increased density of fish if farming moves into a new area), escapees and their impacts on the host biodiversity, and pollution from the materials used to for the cages. These impacts may lead to conflict with other resource users due to the impact on water quality and access to the water resource for activities such as fishing. Examples of the second limitation include contamination of the cultured fish by pollutants such as sewage and heavy metals; aquatic weeds; and importation of brood stocks, which may lead to disease, with the tilapia virus being a major threat to cage culture in East Africa (Farm Africa, 2018; Njiru *et al.*, 2018; Obwanga and Lewo, 2017; Obwanga *et al.*, 2018). Better understanding of feed and seed quality requirements; stocking densities; size, sex and biology of fish; and tolerance to water quality will lead to successful highly commercialised cage culture (Njiru *et al.*, 2018). In *Categories 2 and 3: Medium and low commercialised cages,* farming is sometimes carried out in smaller water bodies than Lake Victoria, and therefore the sustainability is lower given the temporary and rapidly changing nature of such water bodies due to drought and flood. In the past, theft and vandalism of installations and the product, especially close to harvesting, has led to losses in these categories. Cheap material may be used to construct cages; hence, they are not as durable and the chance of the materials causing pollution issues is higher.

In *Category 4: Highly commercialised ponds*, several environmental factors may affect production. Water is the key environmental factor, given the large volumes of it required for such enterprises. Hence, issues of water quality and quantity; conflict with other water users; unpredictable weather patterns; and contamination by pests, diseases and pollutants from watershed are all very urgent. For instance, highly commercialised farming in Kirinyaga county competes for scarce water with rice farming, yet this water may be contaminated with pesticides and fertilisers from rice farms upstream reaching the fish farms downstream (Obwanga and Lewo, 2017; Opiyo *et al.*, 2018). Climatic conditions dictate fish production such that average water temperatures of below 25 ^{o}C result in smaller fish at harvest (Opiyo *et al.*, 2018). This kind of production is vulnerable to challenges related to climate change.

Categories 5 and 6: Medium and low commercialised ponds face similar challenges as described for *Category 4*: threats from predators, altered rainfall patterns, droughts and flooding (Farm Africa, 2018). In addition, farmers also use cheap, poor quality homemade fish feed which pollutes the water in the fishponds. They also use feed for other livestock (e.g. pigs and poultry) which is supplemented with antibiotics, probiotics and growth promoters that are not targeted for fish. These negatively affect fish and other organisms in the aquatic environment. The significant difference in dietary requirements between fish and other livestock also make the use of such diets for fish inefficient, leading to wastage of feed, poor growth and deformities in addition to nutritional disease (Opiyo *et al.*, 2018).

Category 7: Highly commercialised tanks farming is mostly carried out in controlled conditions; hence, farming can be done all year. However, high levels of management skill are required to maintain high standards of water quality, prevent diseases and parasites and feed the fish properly. Inputs such as feed and fingerlings have to be of high quality to assure profitable harvests. Since this system is controlled, it is protected from environmental stresses such as drastic changes in water temperature, predators and theft. In *Categories 8 and 9: Medium and low commercialised tanks*, the technology used improvised and may not be sustainable. Water shortages, poor water quality and attacks of disease are a common occurrence due to poor technology being used. However, these categories maximise use of space in backyards that may be set up on quarter-acre plots or less.

8 Discussing enabling factors as opportunities for investment

In general, performances in the aquaculture value chain in Kenya are improving. Input providers (fingerlings and feed), producers, extension providers and researchers are the most prominent value chain actors and service providers in the sector. Farmers, feed suppliers and fingerling producers have increased in number since 2009, after the GoK supported aquaculture through the ESP. There are currently 24 approved feed suppliers, of which six import feed, and about 127 registered hatcheries. The private sector has emerged to play a key role in fry and fingerling production, contributing about 69.7% of fingerling supply, with the GoK contributing the remaining 30.3% in the years 2010–2016 (Opiyo *et al.*, 2018). Despite the growth of the feed and seed sectors, the regulation of the industry is weak, resulting in poor quality fingerlings and feed being common. The GoK is the key source for knowledge provision (extension and training), although there are insufficient staff and those people are often overstretched. To cover this gap, unregulated private extension services are emerging. The volumes of farmed fish are not enough to support processing; hence, the processing component in the value chain is still in its infancy. Financial support is still minimal, as aquaculture is regarded as a high-risk endeavour. This trend is changing, however, because active participation of the private sector is increasing as the potential for profitability increases. Openness to exchange and collaboration (e.g. Kamuthanga, Unga) and to research, training and technology transfer within the private sector (e.g. via CASK) improves future opportunities for profitability even more. As part of this trend, the sector has increased volumes and reduced production costs to become more competitive and better coordinated and more able to influence policy. The sector also benefits from candid discussions between GoK and stakeholders in different platforms.

The household survey has illustrated that levels of commercialization differ across categories and that it is not possible to deal with the aquaculture sector as homogeneous. The enabling factors of the cages are very much related to the increased interest in investing in Lake Victoria to establish opportunities in a sector that is expected to expand in future, aid by the fact that fish farming in this sector takes place in the warmest part of the country. Although there are fewer opportunities to expand stocking intensity in this sector than in the others, there is room for increase (Figure 11), and they have the lowest share of farmers taking part in the ESP (Figure 21), thus the largest share of farmers who are taking out loans (Figure 20). Although these enabling factors for the cage farmers are supportive to this system, the literature cautions that cage culture may turn into an environmental disaster if not managed well, and there is need for robust policies and increased awareness to reduce environmental impacts (Njiru *et al.*, 2018).

The pond system has very different characteristics, being located mostly in the colder areas of Kenya, which makes it less productive than it could have been in the warmer areas (Figure 6). These farmers are generally older and thus less willing to change, score low on gross margin (Figure 10), make use of more variable sources of water (Figure 14), sell more extensively at the farm gate (Figure 15) and a larger share of their fish meals come from fish they have farmed themselves (Figure 16). However, they have better access to their own transport (Figure 18), larger production systems than cage farmers (Figure 8), and command relatively higher prices for their produce (Table 4). The pond farmers took more extensive part in the ESP (Figure 21) and interacted frequently with extension services (Figure 22). The most enabling factor is the orientation towards food security and nutrition of pond farming, involving the old and the poor, although the relatively low level of commercialization increases the risk of negative environmental effects, by for instance use of bad (sometimes poisoning) feed that not only pollutes the environment but also increases risks for food safety.

The tank system is supported by very different enabling factors. As advanced technologies are needed, tank farmers are required to make huge investments. While the sample included in this survey is small, it covers a large share of the sector because the total number of tank farmers is relatively small. This sector operates at a different scale to the others, with much higher gross margins (Figure 10), incomes, variable costs, values of production systems (Table 3), production of fingerlings (Figure 12), costs of sinking/floating pellets (Figure 13), access to transport (Figure 18), and preparedness to take risks (Figure 19). Apart from the high investment needed to be part of this sector, updated governance is needed, which is challenging given its fast and high level of advancement.

It is clear from Figure 8 that even within the relatively large samples for cages and ponds, there is a great deal of variability within each category, even when extreme outliers are removed. This shows that the sector is experimenting across multiple opportunities, does not follow a structured path, but makes use of emerging opportunities with trial and error. This confirms that the sector is in an experimental phase, which is crucial for transition towards enhanced sustainability and resilience in future (Geels, 2011; Rauschmayer *et al.*, 2015; Soma *et al.*, 2018b).

Based on the categorisation of farmers according to production system and commercialization level (Figure 7) and estimates of a selection of core indicators investigated by a household survey in this study (Table 1), it has been shown that most variables do fit an expected trend according to the different commercialization levels. However, some results were different from expected. Table 5 shows the extent to which the trends set out in Table 1 are supported or not.

Table 5: Summary of key enabling factors to be considered for defining investment strategy per commercialization category

Selected food system indicators	Low, medium and high commercialization level of cage, ponds and tanks
Income (KES)	The income estimates in Table 3, as well as the gross margin values in Figure 10, fit with the expected trends in Table 1, with higher values for higher levels of commercialization.
Fingerlings produced (number of pieces)	For fingerlings, the increasing trend stated in Table 1 is very true for the tank farmers, who are overall the largest producers (Figure 12); however, in the cage categories, the medium commercialization level contributes the most to fingerling production.
Inputs (floating pellets)	Looking at the costs of floating pellets (Figure 13), this variable follows the trend expected for all production systems in Table 1. Notably, the overall costs of the medium and highly commercialised tank categories are relatively a lot higher than for any other category.
Market outlets (% per outlet category)	While for cage and tank farmers the variety of market outlets is larger for the highly commercialised compared with lower commercialization levels within the same production system (Figure 15), this is not the case for pond farmers for which the medium commercialised category has the highest variability.
Transport (% of farmers with own transport)	Although the trend is confirmed as expected from low to high commercialization levels for ponds and cages, it is striking that the cage farmers have relatively low access to their own transport because they need to transport fish from Lake Victoria to market outlets (Figure 18). Also, it is surprising that the highly commercialised tank farmers do not follow the trend expected, as they often can make sales close by or on the farm site itself.
Share of fish meals consumed per household (%)	This variable follows (Figure 16) the trend expected in Table 1, except that the medium commercialised tank farmers consume more meals from their own fish production than the low commercialised tank farmers.
Risk-taking/aversion	The pattern of higher risk taking with higher levels of commercialization is not confirmed by the findings in the survey for ponds or tanks, only for cages. Notably, risk aversion is observed for cage and pond farmers and most so for the low commercialised farmers, but also for the highly commercialised ponds

Selected food system indicators	Low, medium and high commercialization level of cage, ponds and tanks
(perception ranking)	(Figure 19). Overall, the tank farmers seem to be the most risk-taking segment of the aquaculture sector in Kenya.
Trust in government (perception ranking)	The presumed trend is not confirmed by the results from the household survey for trust in government (Figure 23). However, the low trust levels in the highly commercialised cages and low commercialised tanks categories match with the categories that received the least government support, while the low commercialised ponds category has a high trust level and received the most support (Figure 21), which may be the explanation.

In the household survey, past investments and financial support were identified for the nine categories (Figure 20). While farmer investments are relatively high for all categories, it appears that the cage farmers take out more loans than the other categories, and the pond farmers have received relatively more government support than the other categories. Also, the cage farmers are, to a high extent, getting support from banks, thus financial markets. The experiences of return on investment may be crucial to understanding how investments can lead to viability of the sector in future. One argument for this is that the most urgent enabling factors must get more attention to removed obstacles to further development. Based on the analyses conducted in this survey, Table 6 shows the core enabling factors to be considered for future investments in the nine different commercialization categories.

Table 6: List of core enabling factors to be considered for future investments in the nine different commercialization categories

	Cages	Ponds	Tanks
High	**Category 1** • Transport with cooling systems to carry fish to long-distance markets • Strategies to compete with low-priced imports of Chinese tilapia • Maximize on profit when investment costs are high • Stable supply of high-quality fingerlings and feed • Collaborative tailormade training • Improved management and regulations/policies for new fast-growing category • Conflict management and business integration of competing resource users (e.g. Beach Management Units) • Fish handling and processing training • Environmental management to avoid pollution, diseases, loss in biodiversity	**Category 4** • Supply of good fingerlings and feed • Extension services for advancing semi-intensive fish farming • Opportunities for both men and women • Environmental management to ensure water quality and quantity and adaptation to climate change • Access to target markets, with value-added products and services such as filleting, in the urban areas and supermarkets • Strategies to handle unpredictable weather patterns, contamination by pests and diseases, pollution from watersheds (e.g. from rice production) • Conflict management of competing resource users • More areas available for this business category	**Category 7** • Increased quantity and improved quality of feed and seed • Expertise and high skill in operating RAS • Strategies to keep production costs low • Strategies for marketing in urban and peri-urban areas • Strategies to compete with low-priced imports of Chinese tilapia • Improved and updated management and regulations for new fast-growing business category
Medium	**Category 2** • Stable supply of high-quality fingerlings and feed • Well-established self-help groups (youth and women) and cooperation among farmers familiar with local possibilities • Participative strategies for individuals excluded from established network • Improved management and regulations/policies for new fast-growing category • Conflict management of competing resource users • Environmental management to avoid pollution, diseases, loss in biodiversity • Local market facilities	**Category 5** • High-quality commercial feed and improved use of fertilisers • Strategies to target markets at the farm gate • Strategies to handle unpredictable weather patterns, contamination by pests and diseases, pollution from watersheds (e.g. from rice production) • Environmental management to ensure water quality and quantity and adaptation to climate change • Equipment to increase productivity	**Category 8** • Strategies for new innovations (e.g. use of insect larvae as feed) and business models (e.g. use of apps and social media) to be brought forward • Access to extension, technical support and training at appropriate knowledge level • Marketing in urban and peri-urban areas • Accessibility to sustainable technologies • Environmental management to ensure water quality and quantity • Management and regulations for new fast-growing sector

	Cages	Ponds	Tanks
Low	**Category 3** • Enabling factors as reported for Category 2	**Category 6** • Stimulate more stable production volumes and higher harvest weights • Stimulate use of high-quality commercial feed • Extension services to ensure job creation for young people as well as support to old people • Poverty alleviation and food security • Strategies to handle unpredictable weather patterns, contamination by pests and diseases, pollution by watersheds (e.g. from rice production) • Environmental management to ensure water quality and quantity and adaptation to climate change	**Category 9** • Enabling factors as reported for Category 2

Based on the literature reviews undertaken about the different areas of the analytical food system framework (Figure 1), the findings are now briefly assessed and summarised in Table 7. It is illustrated that for **input and production variables**, highly commercialised categories are performing relatively well for cages, ponds and tanks (Categories 1, 4, 7), as well as for the medium and low commercialised categories of tanks (Categories 8, 9). In contrast, the low commercialised pond farmers (Category 6) are facing the biggest bottlenecks for food production, due to low levels of inputs and outputs, urgent poverty and food security issues, and low sustaining markets. Medium and low commercialised cage farms (Categories 2, 3) are performing relatively well due to the role of the cooperatives and self-help groups (young people and women) in reducing individual risks and marketing the products together, and medium commercialised ponds (Category 5) are obtaining similar benefits by operating in clusters to ensure consistency in supply. However, commercial feed is out of reach to this group, and because they lack choices, they use pig pellets and poultry feed, which with the use of organic and inorganic fertilisers, cause high levels of pollution due to ineffectiveness in input use.

For the **transport, sales, losses and consumption variables**, the highly commercialised farmers at Lake Victoria (Category 1) are facing serious challenges due to the need for expensive cooling for transport and high competition by imported cheap Chinese tilapia. The medium and low commercialised cage farmers are benefiting from the self-help groups, which play an important role in selling fish locally, such as during market days. The low commercialised cage farmers (Category 3) and the highly commercialised pond farmers (Category 4), have high potential to farm and supply in urban and semi-urban areas. The medium and low commercialised pond farmers (Categories 5, 6) and low commercialised tank farmers (Category 9) sell at their farm gate, often at very low prices. While the highly and medium commercialised tank farmers have good links with high-end markets, they are challenged by imported Chinese tilapia. The medium category also makes use of social media, mobile apps and personal networks.

In the case of the **institutional governance variables**, the medium and low commercialised levels of cage farming (Categories 2, 3) are performing relatively well due to the role of the cooperatives and self-help groups. In contrast, the highly commercialised cage, pond and all tank farmers (categories 1, 4, 7, 8, 9) face challenges because they are developing faster than the institutions are adapting to their needs, with weaknesses in managing, for instance, effluents and water usage. Medium and low commercialised pond farms (Categories 5, 6) have received extension services from the GoK for poverty alleviation and job extension purposes, which remain core issues in these categories.

The **socioeconomic/inclusiveness enabling factors** score high for all cage and most pond farmers (Categories 1, 2, 3, 4, 5) because of the growth this sector provides in employment opportunities and the role of cooperatives and self-help groups and clusters. This is not really the case for the low commercialised pond farmers (Category 6). For tank farming (Categories 7, 8, 9), the investment costs are very high and technology makes the work efficient and precise; only a few people are able to be employed in this sector.

The **external environmental/climate enabling factors** are critical to most categories. Impacts on biodiversity and of pollution, including heavy metal poisoning, are issues mainly for the highly and medium commercialised cage farmers operating in Lake Victoria (Categories 1, 2), while pollution is the most relevant environmental issue for the low commercialised cage farmers (Category 3). The pond farmers (Categories 4, 5, 6) have serious challenges with water quantity and quality, conflict among different user groups, unpredictable weather patterns, contamination by pesticides and fertilisers from rice farms upstream of fish farms, and are particularly vulnerable to climate change. Medium and low commercialised pond farmers (Categories 5, 6), use cheap, homemade low-quality fish or alternative livestock feed, which is supplemented with antibiotics, probiotics and growth promoters. This is not only ineffective but causes deformities and nutritional diseases in fish. The highly commercialised tank farmers (Category 7) operate in controlled conditions and are protected from environmental stresses. In the other tank categories (Categories 8, 9), water shortages and poor water quality, which result in fish disease, are relevant issues. Table 7 summarise core findings based on the best practices revealed in the literature reviews. Red refers to urgent bottlenecks, yellow to issues of relatively low urgency, and green refers to operational enabling factors. The categories are named in Figure 7.

Table 7: Performances of each category across value chains and broader food systems

Category	Inputs and production variables	Transport, sales, losses and consumption variables	Institutional governance variables	Socioeconomic / inclusiveness enabling factors	Environmental / climate enabling factors
1					
2					
3					
4					
5					
6					
7					
8					
9					

9 Conclusion

A growing population, improvement in socioeconomic conditions resulting in rising demand for fish by a rapidly emergent middle-class population, increasing prices and dwindling supplies of wild-caught fish are explanatory factors for the expansion of the aquaculture sector in various parts of SSA, including Kenya (Kaminski *et al*., 2018; Obwanga *et al*., 2018). The sector is commercialising, although government support still plays a crucial role. Given the high demand for and concerns about food security in the whole region, advancements of more integrated and effective aquaculture value chains are welcomed in future. Further commercialisation is expected to contribute to enhanced viability of the sector. Accordingly, the main aim of this report was to explore core enabling factors for commercialisation of the aquaculture sector in Kenya, based on a structured household survey and a qualitative literature survey, applying an analytical food system approach that includes the supply chain and consumers.

Based on recommendations made by core stakeholders (Koge *et al*., 2018), 300 farmers were selected for interview. Most of these farmers had aquaculture systems in ponds (199), followed by cages (81) and tanks (20). The criteria for selection were based on the need for diversity across locations (close to Nairobi and Lake Victoria), as well as diversity across characteristics such as 1) value chain enabling factors such as supply to market (e.g. on-farm sale, local market, urban market, export), 2) environmental constraints (e.g. issues of water shortage, biodiversity loss, pollution), and 3) need for infrastructure (e.g. distance to market, own transport possibilities, cooling). Given the discrepancies across and within different segments using cages, ponds and tanks, it was critically important to categorise them according to commercialisation levels. The categorisation was based on existing approaches (see Chapter 2).

Although the household survey investigated an extensive number of variables (about 30), seven indicators were selected (Table 1) to assign expected trends across low, medium and high commercialisation levels of cage, pond and tank farmers. The specific indicators analysed are: income (in Kenyan Shillings [KES]), fingerling production [numbers], fish feed (floating pellets [tons]), transport (% of farmers who have their own transport), market outlets (% per outlet category), share of fish meals consumed per household (%), risk taking/aversion (perception ranking) and trust in government (perception ranking). The summary of their performances is provided in Table 5. While income, costs of inputs and share of fish meals consumed from own produce follow an expected increasing trend from low to high commercialisation levels, this is not the case for all variables. For instance, even though for ponds and tanks the expected increasing trend from low to high commercialisation level is confirmed, for cages, the medium commercialised farmers are producing more fingerlings than the highly commercialised farmers. Also, in the case of access to transport, the increasing trend from low to high commercialisation levels is confirmed for cages and ponds, but not for tanks. This is explained by consumers purchasing the fish close to the tanks. The expected trend for market outlets was increased variability at higher levels of commercialisation; this was confirmed for cages and tanks, but not for ponds, for which the medium commercialisation level has the highest variability. The expected trends of higher risk-taking perception at higher levels of commercialisation was confirmed among cage farmers, but not for the pond and the tank farmers. No links between trust in government and commercialisation levels can be seen directly, but it appears that the categories supported more extensively through the government ESP have the highest trust in the government, and the ones receiving less have relatively low trust levels.

While the structured household survey interviewed farmers about the farm and the value chains they belong to, an analytical food system framework for aquaculture was applied to address dimensions beyond the aquaculture value chain. This is because best practice and enabling factors for the aquaculture sector often depend on external activities such as capacity-building, government support and/or banks providing financial loans. The food system approach recognises that socioeconomic, inclusiveness, environmental and climate enabling factors affect the outcomes of a food system.

A literature review was conducted to examine external activities and enabling factors to explore their importance to the aquaculture commercialisation opportunities across different cages, ponds and tank categories. In was found that the share of private investment is highest in cage farming. While tanks also are commercialising extensively, they still depend on government support at this early stage in development. The pond categories are still attracting government funds more extensively, and in this segment the inclusiveness, nutrition, food security and food safety issues are more critical than issues of commercialisation, at least for the less commercialised categories. Notably, the structured household survey confirms that the least commercialised pond farmers also profit aquaculture production.

An urgent enabling factor for the sector overall is the lack of stability in input supply (fingerlings and pellets). Moreover, the supply of Chinese tilapia is a critical potential threat, although this is not necessarily a major concern for the sector. Further, the issues of infrastructure and cooling systems are relevant to all categories. Another issue, particularly for cage farming, which is booming in Lake Victoria, is that implementation of guidelines and regulations that ensure environmental protection is weak or lacking. For the ponds, especially the low commercialised category, the issue of healthy or sustainable feed is urgent, which is linked to poverty alleviation and food security. Tank farmers need to take a critical step forward to ensure that businesses obtain levels of commercialisation where they can operate without any form of subsidy and can provide large amounts of fingerling and fish supply to ensure stability in the market. Based on high effectiveness of use of water and feed, they can offer this in RAS, making use of technology with low environmental and climate impacts.

To proceed with urgently needed steps forward that will make it possible for the aquaculture sector to provide an ever-growing population with their future protein needs, investment is needed. The core enabling factors in the aquaculture sector in Kenya need to be investigated to find the extent to which cage, pond and tank farmers are eager to change to robust, reliable and resilient food system activities. These enabling factors are:

- use of the most appropriate feed, which depends on availability of feed producing/importing companies, choice of different types of feed (sinking or floating pellets), feed quality, prices and production
- use of fingerlings, which depends on availability of public and private hatcheries, quality, prices and production capacity
- improved institutions, regulations and governance, as well as capacity-building and training to support the viability of the sector
- improvements in infrastructure for cooling and hygiene that can enhance product quality and support the sector
- certified products to allow consumers to know specific qualities of products as well as whether they are buying Chinese or Kenyan farmed fish.

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Annex: Detailed list of variable costs per category (KES/year)

Cage		Low	Medium	High
	Antibiotics		60	40
	Disinfection	150	784	92
	Anthelmintic	840	138	208
	Storage	325	690	23,520
	Transportation	800	2,481	8,710
	Extension			1,000
	Hired labour	1,092	44,889	79,723
	Renting in land			128,500
	water body payment	2,850	3,617	6,984
	Tilapia fingerlings	18,967	23,995	48,770
	Own-produced tilapia fingerlings		93,000	
	Feed cost	27,475	70,329	121,098
	Maintenance	9,900	13,063	9,620
	Sum	**62,399**	**253,046**	**428,265**
Pond	Antibiotics		280	
	Organic fertiliser	230	302	86
	Inorganic fertiliser	796	1,033	821
	Disinfection	461	1,802	954
	Anthelmintic	530	5,125	790
	Water cost	1,000	1,326	3,429
	Storage	583	2,069	1,480
	Transportation	603	2,419	16,224
	Extension	172	177	186
	Hired labour	4,224	10,731	72,460
	Renting in land	32,339	15,273	26,590
	Tilapia fingerlings	6,919	16,463	24,278
	Catfish fingerlings	9,642	13,380	21,303
	Own-produced tilapia fingerlings			10,500
	Own-produced catfish fingerlings		65,000	11,850
	Other fingerlings		80,000	10,000
	Feed cost	13,108	36,179	89,227
	Maintenance	7,587	9,149	16,045
	Sum	**78,194**	**260,708**	**306,223**
Tank	Antibiotics		1,000	3,000
	Organic fertiliser			2,667
	Inorganic fertiliser		11,233	11,975
	Disinfection	450	1,080	3,220
	Anthelmintic		300	11,133
	Water	6,000	60,750	49,200
	Storage	15,067	73,100	58,813
	Transportation	20,000	129,000	158,200
	Hired labour	93,854	431,836	417,600
	Tilapia fingerlings	20,000	218,250	300,000
	Catfish fingerlings	1,000	7,000	800,000
	Trout fingerlings		21,000	1,000,000
	Own-produced tilapia fingerlings	28,000	390,938	221,250
	Own-produced catfish fingerlings		761,500	143,333
	Other fingerlings		288,000	
	Feed cost	26,740	678,495	2,650,750
	Maintenance	85,000	301,525	145,579
	Sum	**296,111**	**3,375,007**	**5,976,720**

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The Centre for Development Innovation works on processes of innovation and change in the areas of food and nutrition security, adaptive agriculture, sustainable markets, ecosystem governance, and conflict, disaster and reconstruction. It is an interdisciplinary and internationally focused unit of Wageningen UR within the Social Sciences Group. Our work fosters collaboration between citizens, governments, businesses, NGOs, and the scientific community. Our worldwide network of partners and clients links with us to help facilitate innovation, create capacities for change and broker knowledge.

The mission of Wageningen UR (University & Research centre) is 'To explore the potential of nature to improve the quality of life'. Within Wageningen UR, nine specialised research institutes of the DLO Foundation have joined forces with Wageningen University to help answer the most important questions in the domain of healthy food and living environment. With approximately 30 locations, 6,000 members of staff and 9,000 students, Wageningen UR is one of the leading organisations in its domain worldwide. The integral approach to problems and the cooperation between the various disciplines are at the heart of the unique Wageningen Approach.