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A review of the performance of fish seed systems in Africa

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A review of the performance of fish seed systems in Africa

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Abstract

Globally, fish is one of the most important sources of animal protein and a key source of livelihood. In Africa, fish production has significantly increased in recent years, but the proportion of fish production relative to other regions is extremely low. In most African countries, the aquaculture sector is poorly developed. With a lack of access to quality seed commonly cited as a key constraint to fish production, interventions in fish seed systems could ensure fish seed security for the majority of the farmers in Africa.

This study seeks to synthesize the available evidence on fish seed systems using a systematic literature review. The review combines a multistakeholder framework and seed system components approach to characterize and analyze the performance of the fish seed systems in Africa. The study highlights the major constraints facing fish seed systems in Africa. Most governments operate public hatcheries and aquaculture stations, but they are highly inefficient. Lack of standards and weak enforcement where standards do exist have led to farmers accessing poor-quality seeds when seeking alternative sources of seed. Demand for improved seed is high, but the existing formal seed system cannot supply quality seed to farmers at the right time. Farmers, therefore, rely on the informal sector, getting seed from the wild or smallholder seed multipliers.

Tilapia fry, Egypt.

Introduction

The capture fisheries and aquaculture sector is one of the most important sources of food globally. According to the Food and Agriculture Organization (FAO) (2020), about 179 million metric tons of fish were produced in 2018, of which more than 87% (156 million metric tons) were used for human consumption, making food fish one of the most important sources of animal protein globally. Per capita fish consumption has increased consistently from 9 kg (live weight equivalent) in 1961 to 20.5 kg in 2018 (FAO 2020).

Beyond the supply of food, the capture fisheries and aquaculture sector is also a key source of livelihood. In 2018, the sector is estimated to have employed 59.51 million people, of which about 85% were employed in Asia (FAO 2020). Filipski and Belton (2018) were able to determine that "aquaculture generates much higher incomes per-acre than agriculture and generates larger income spillovers than agriculture for non-farm households by way of retail and labor markets." Thus, aquaculture can be very effective in reducing poverty and increasing rural incomes. The proportion of global food fish from aquaculture has increased from less than 10% five decades ago to approximately 52% in 2018 (FAO 2020). The increased role of aquaculture has contributed to better nutrition and food security for regions and countries with limited access to cultured fish species through access to fish at cheaper prices.

Africa accounts for approximately 2.7% of global aquaculture production. The value of this production is equivalent to only 1.3% of total global value (FAO 2020). The leading aquaculture producers on the continent are Egypt, Nigeria, Uganda, Ghana, Tunisia, Kenya, Zambia, Madagascar, Malawi and South Africa (Adeleke et al. 2020). Egypt is the leading producer of aquaculture in Africa and the third-largest producer of tilapia in the world after China and Indonesia (FAO 2018). Sub-Saharan Africa accounted for only 0.75% of aquaculture production in 2014 (FAO 2016). Nevertheless, production increased seven-fold over a period of 10 years, from 80,900 t in 2004 to 556,950 t in 2014, representing an annual increase of 21%. About 90% of Africa's aquaculture output is produced by Egypt, Nigeria and Uganda (Adeleke et al. 2020). However, this growth has hardly kept pace with population growth and demand for fish, with consumption dropping from 10.5 kg in 2014 to 9.9 kg in 2017 (Brummett 2007; FAO 2020).

Brummett et al. (2008) described the poor performance of aquaculture in Africa as a mystery. This is because aquaculture production on the continent has lagged despite Africa being been one of the highest recipients of donor funding in the world (Obwanga et al. 2020). For instance, Lazard et al. (1991) found that African aquaculture development received three-fold funding relative to Asia and the Pacific from 1978 to 1984, but Asian countries produced 1000 times more fish than Africa (Brummett et al. 2008). Between 2009 and 2013, the Kenyan government through its Economic Stimulus Programme (ESP) invested approximately USD 220 million in the aquaculture sector. Yet within 5 years, the majority of farmers under the ESP had completely or partially abandoned their fishponds, citing various challenges (Musyoka and Mutia 2016).

One of the most cited problems facing aquaculture in Africa is the unavailability of quality fish seed (AIFP 2005; Brummett et al. 2008; Pouomogne and Pemsl. 2008; Satia 2015; Musyoka and Mutia 2016). Like all other agriculture and food production sectors, the availability of seeds of the right quality, as and when needed, is a key prerequisite for production (Kramer and Galiè 2020). Seed supply systems can be used to deliver productivity, gender equity, nutrition and climate adaptation to farmers of all sectors (Thomas 2008; Bouis and Welch 2010; McGuire and Sperlin 2013; Shikuku et al. 2019). An assessment of the effect of access to quality disease-free planting materials of orange sweet potato showed an improvement in welfare indicators for households, including food security status (Shikuku et al. 2019). Seed systems could improve nutrition by increasing productivity and household income, or production of nutritious food that is consumed by the household.

The Integrated Seed Systems Development (ISSD) approach recognizes the relevance of a pluralistic and integrated method for developing a seed system. The ISSD approach considers the totality of the structure of the system, identifying areas of informal and formal sector participation, as well as public and private sector involvement (Munyi and De Jonge 2015). By strengthening multiple seed systems, the ISSD approach can combine different objectives, such as food security, entrepreneurship development, agricultural development and biodiversity management (Louwaars et al. 2013; Munyi and De Jonge 2015). In implementing the approach, the range of existing and formal and informal viable seed systems is identified and characterized according to the structure of the seed value chain to promote the diversity of seed businesses that thrive within their specific niches (Louwaars et al. 2013; Munyi and De Jonge 2015).

Globally, various innovations and technologies have improved the quality of fish seed in use, as well as the resulting productivity. For example, the invention of the Genetically Improved Farmed Tilapia (GIFT) technology to produce monosex (all male) fry has considerably increased the production of tilapia species in many Asian countries (Nguyen et al. 2007; Alam et al. 2019; Shikuku et al. 2021). The GIFT strain was developed by World Fish and partners to improve the supply of tilapia seed and the performance of aquaculture. Selective breeding is the main technique that was used to develop the fast-growing GIFT strains (WorldFish 2015).

In Africa, low fish seed supply has persisted despite huge capital investment into hatcheries from foreign donors and governments (Brummett 2007; Brummett et al. 2008; Musyoka and Mutia 2016). Fish seed supply in Africa is erratic and unreliable, such that farmers are unable to access the required quantity or the right quality when and where they need them. A big proportion of government and donor funding has gone into setting up public hatcheries and/or aquaculture stations, the majority of which become dysfunctional after a short while (Brummett 2007; Musyoka and Mutia 2016). In addition, most African farmers are growing fish of poor genotypic and/or phenotypic quality, which results in poor performance (Brummett et al. 2008). On top of all this, improved species and/or strains that are available in other regions have not been popularized in Africa due to concerns for biodiversity (Brummett et al. 2008). Improved breeding can increase aquaculture yield by 5.6% to 49%, depending on the species of fish and type of improvements (Yu et al. 2021), an indication of the production losses fish farmers in Africa incur when they do not grow improved breeds.

Despite the fundamental role of fish seed systems in the aquaculture sector, and the evident poor performance of the seed sector, fish seed systems in Africa are poorly documented and the literature on them is scant. There are hardly any empirical studies on fish seed systems in Africa. Available studies are few and not comprehensive enough, only providing a minimal descriptive analysis of the sources of fish seed in selected countries. The reported findings are mixed and refer to specific locations on the continent, which make them difficult to synthesize comprehensively. In such cases, a systematic review of available studies is a suitable method to synthesize the current evidence. The objective of this systematic review, therefore, is to synthesize the available evidence on fish seed systems in Africa. In particular, the review analyzes both formal and informal systems and evaluates the organization of the value chain.

1. Methodology

1.1. Search strategy and selection criteria

The literature review on fish seed systems in Africa was conducted using a systematic literature review approach. The search was carried out in July 2021, using databases that include ScienceDirect, Taylor and Francis, JSTOR, WorldFish repository, the FAO website and Google Scholar, among others, to capture comprehensive literature on fish seed systems in Africa. Using Boolean operators, each search paired different combinations of terms related to the fishery, aquaculture and fish seed systems in Africa. The terms for inclusion were aquaculture development, fish farming in Africa, fish seed systems, and fish value chain. The general search included synonyms, other ways to spell the keywords, and words related to the search terms. The search in specific journal articles ensured we included additional records that might have been skipped during the initial search.

We outlined the inclusion and exclusion criteria for our study. The review considered articles that were available in English. It included research articles and reports on aquaculture in Africa but focused on fish seed systems, characterizing and evaluating the performance of different fish seed system components. The study did not consider the publication period. First, we excluded duplicates. Then we screened by title and abstract to eliminate articles that were not eligible for review. A full-text review of the remaining articles was done to ensure that only quality eligible articles remained for the data extraction. In total, 37 papers were included in the systematic review (Figure 1).

1.2. Data extraction and analysis

Data from the selected articles was extracted and analyzed using an approach that captured information on the main thematic area emerging for the reviews. Using the results from the analysis, we developed a matrix by focusing on the following fish seed system components: (1) seed production (checking the quality, availability, access, and production capacity), (2) the distribution of fish seed, and (3) the regulatory environment in the fish seed systems. The results are therefore discussed based on the components of the fish seed systems and the actors in the different seed systems.

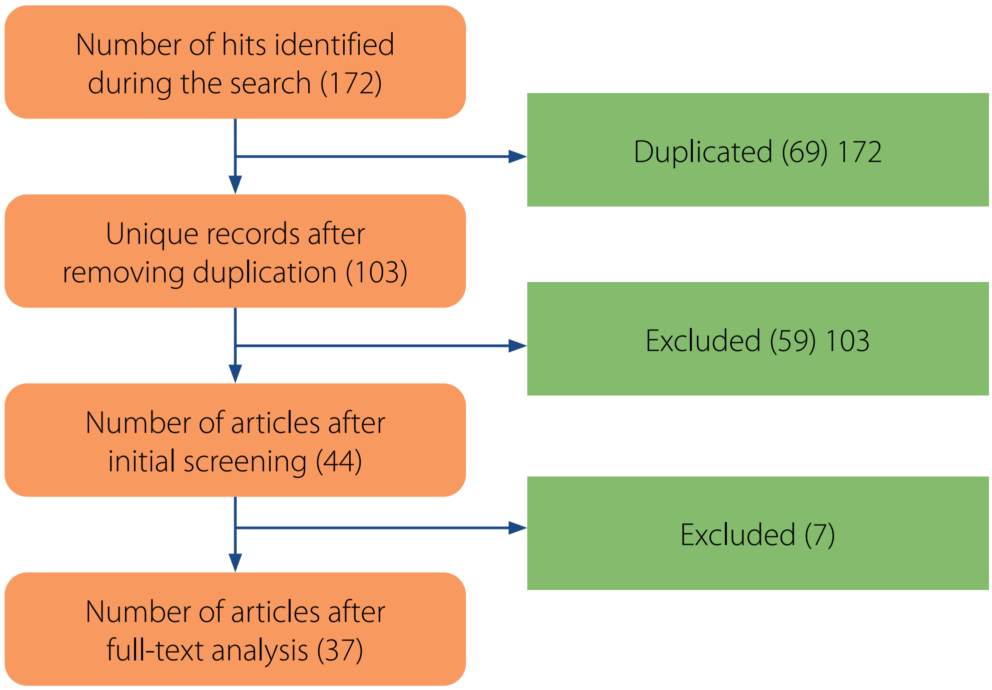

Figure 1. Flowchart showing the inclusion/exclusion criteria.

1.3. Analytical framework

The study combined a multistakeholder perspective with the seed system performance analysis framework to characterize and assess fish seed systems in Africa (Figure 2). Examples of studies that have used a similar approach to analyze the performance of seed systems include Weltzien and Brocke (2001), Hirpa et al. (2010) and Shikuku et al. (2021). The study adopts a multistakeholder approach to answer research questions in the following seed system components:

i. Seed production

a. What are the key sources of fish seed in Africa?

b. What are the popular fish species and/or strains produced from the different fish seed sources?

c. How do the supply parameters, such as quantity, quality and timeliness, match the demand?

d. What are the various technologies and innovations that different value chain actors use?

ii. Seed distribution

a. How efficient are the various fish seed distribution channels in Africa?

b. What are the popular fish species and/or strains produced from the different fish seed sources?

iii. Policy and regulatory framework

a. What is the role of the government compared to the private sector in fish seed production in Africa?

b. How do the fish seed production systems in Africa compare to those in Asia?

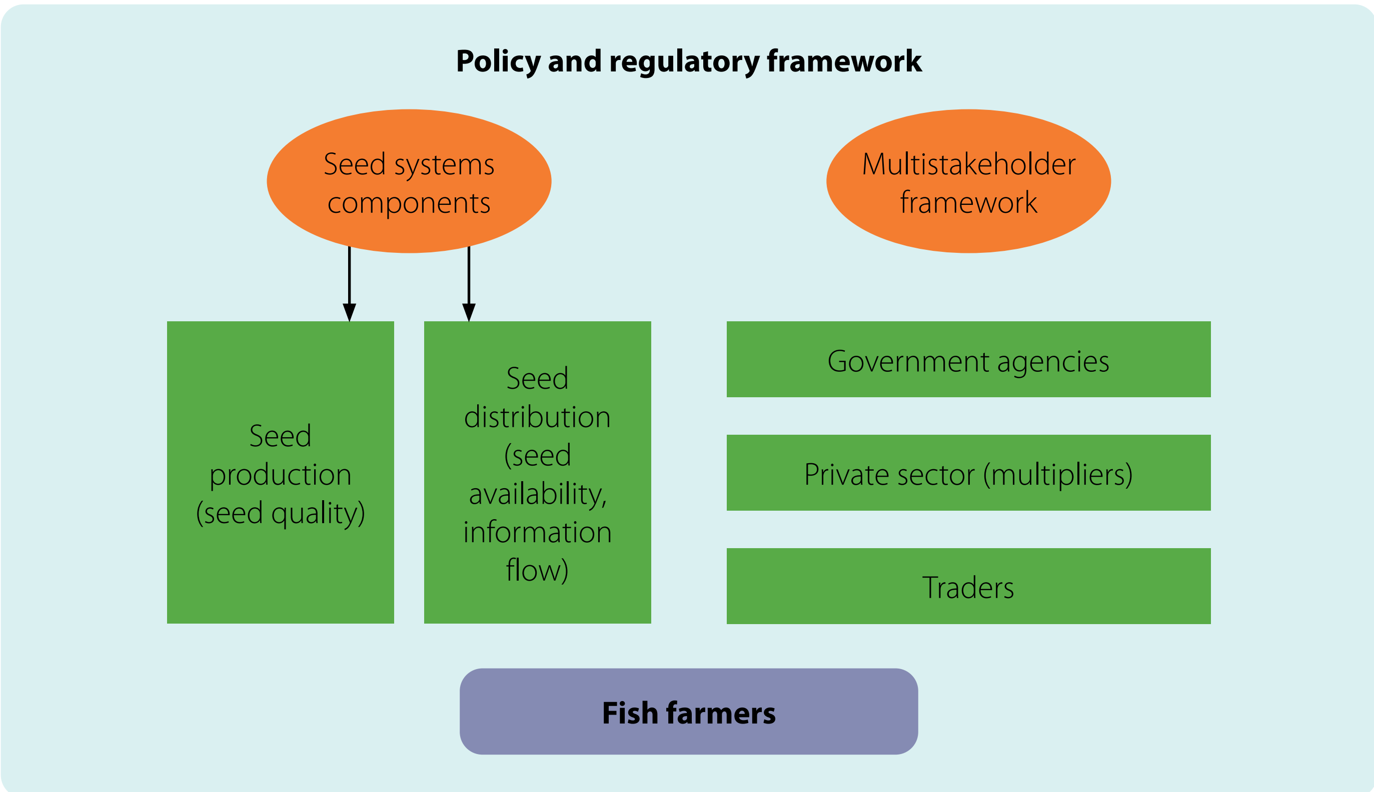

Figure 2. Analytical framework for assessing seed systems.

2. Findings

2.1. Mapping the fish seed value chain and value chain actors

At the start of the fish seed value chain is input supply for fish seed producers, including wild collectors (Figure 3). This involves the supply of inputs used at hatcheries such as fry/fingerling feed, as well as pesticides. Intensive farmers feed the fry hormone-treated food for 3–4 weeks before selling them (Nasr-Allah et al. 2014). In most countries, farmers use a mix of commercially supplied feeds and farm formulated feeds.

The second phase is the broodstock and fry or fingerling production. The actors in this stage can be classified based on the scale of production, sources and the agencies or people involved. The most common producers are commercial (often large-scale) private sector hatcheries, small-scale private sector hatcheries, public sector hatcheries and wild collectors (Figure 4). In most countries, all various production actors exist in parallel, though they target different buyers. The main resource used to produce fry/fingerlings is water, which can be surface (springs, streams, rivers and/or lakes), groundwater (boreholes and wells) or harvested rainwater (Obwanga et al. 2020). Farmers, especially those within temperate zones of African countries, require a power source for heating, such as solar or electricity to fire boilers. Farmers use hapas, concrete tanks or earthen ponds, some of which use plastic liners to slow water loss (Nasr-Allah et al. 2014; Musyoka and Mutia 2016). Using tanks has been identified as the most productive and profitable system in fish seed production (Obwanga et al. 2020).

Figure 3. Simplified fish seed value chain.

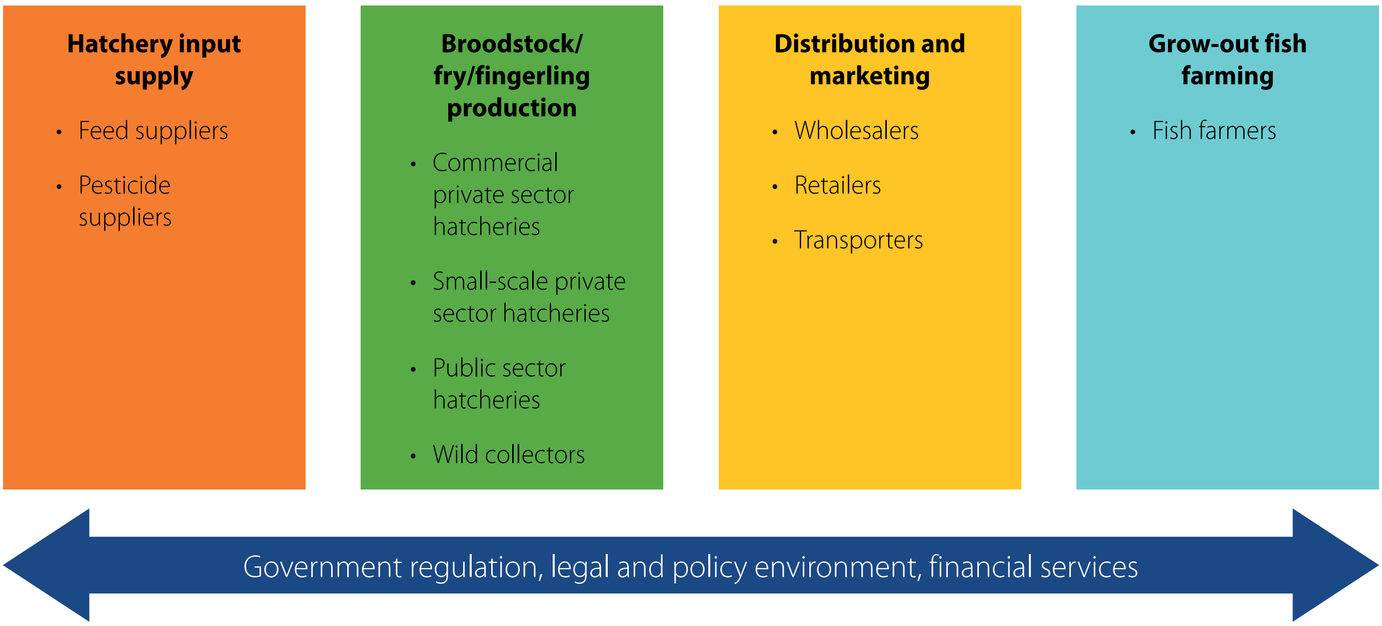

Figure 4. Types of actors along the fish seed value chain.

The main cost commercial hatcheries incur is labor (Macfadyen et al. 2012). In contrast, the highest cost that fish farms incur goes to purchasing fish feed. Compared to fish farms, hatcheries are more profitable (Macfadyen et al. 2012; Nasr-Allah et al. 2014).

Fish seed producers mostly sell their produce in the form of fry or fingerlings. Many of these producers also own fish farms for grow-out production, so they often sell the fry or fingerlings to their own farms (Nasr-Allah et al. 2014). The other buyers are fish traders, either wholesalers or retailers, who in turn sell the fish seed to fish farmers. Some fish seed producers sell directly to fish farmers. Some seed traders stock fry in nursery ponds and grow them for a period to balance supply and demand. For example, traders might purchase fry cheaply at the end of one season and sell them at the beginning of the next growing season when prices are higher (Nasr-Allah et al. 2014).

A farmer in Egypt checks the condition of fry before releasing them.

Study	Production				Distribution and marketing			Government role			Systems in Asian countries
	Sources	Quality	Availability	Technologies	Transportation	Efficiency	Channels	Legal and policy	Seed production	Standards	
Adeleke et al. 2020	√	√	√	√				√	√		
Adewumi 2015	√	√	√	√				√		√	
AIFP 2005	√	√	√	√					√		
Aulanier et al. 2005	√	√	√	√	√		√		√	√	√
Brummett 2007	√	√	√	√		√	√	√	√	√	√
Fachry et al. 2018	√	√	√	√	√		√	√		√	√
FAO 2020a	√	√	√	√	√	√	√	√	√	√	√
FAO 2020b	√		√	√							
FAO 2016	√		√	√							
Filipski and Belton 2018											√
George et al. 2010	√	√	√	√			√	√	√		
Hishamunda et al. 2009	√	√	√	√	√			√	√		√
Komarudin et al. 2010		√		√							√
Kramer and Galiè 2020		√	√								
Louwaars et al. 2013											
Macfadyen et al. 2011	√	√	√	√	√	√	√	√	√	√	
McGuire and Sperling 2013											
Munyi and De Jonge 2015											
Musyoka and Mutia 2016	√	√	√	√		√		√	√		
Mwanja et al. 2015	√	√	√	√	√	√	√	√	√	√	
Nasr-Allah et al. 2020			√								
Nasr-Allah et al. 2014	√	√	√	√	√		√	√	√		
Nyonje et al. 2015	√	√	√	√	√	√	√	√	√	√	
Obwanga et al. 2018	√	√	√	√			√	√	√		
Patnayakuni et al. 2006											
Pouomogne and Pemsl 2008	√	√	√	√	√	√	√	√	√	√	
Quyen et al. 2016	√	√	√	√		√					
Rothuis et al. 2011	√	√	√	√	√			√		√	
Satia 2017	√	√	√	√	√	√	√	√	√	√	√
Shaalan et al. 2018	√	√	√	√				√	√	√	
Shikuku et al. 2021	√	√	√	√	√	√		√		√	√
Shikuku et al. 2019											
Sugama et al. 2014		√		√							
Thomas 2008											
WorldFish 2015	√	√		√							√

Table 1. Analysis of selected studies.

Characteristics	Egypt	Uganda	Kenya	Cameroon	Nigeria	Ghana
Common varieties	Tilapia, carp and catfish	Nile tilapia	Nile tilapia, African catfish, common carp, rainbow trout	Tilapia and catfish	Tilapia, catfish and carp	Akosombo strain of tilapia
Sources	The main sources are private and government-owned hatcheries. Tilapia seed is mainly produced by private hatcheries, while carp seed is produced almost exclusively in government hatcheries for stocking in rice fields and irrigation channels.	Hatchery production	Hatchery production, wild catches	Seed is collected from natural waters (wild sources) and produced in hatcheries. About 25% of the catfish and kanga fingerlings come from the wild.	Seed is imported from natural waters (wild sources) and produced in hatcheries based on controlled spawning.	Hatchery production
Production system	Farmers produce monosex tilapia fry and carp fry in their own hatcheries, while commercial hatcheries are also common. The General Authority for Fish Resources Development (GAFRD) controls the fry trade to avoid black market practices. A total of 411 million units were produced in 2014. Hatcheries use indoor tanks and hapas. Tanks are warmed in winter to raise temperatures.	There are commercial hatcheries of various sizes: small-scale hatcheries have limited capacity and produce 200,000–300,000 units annually for rural communities; medium-scale hatcheries sell to emerging commercial farmers within the district, with a capacity of 300,000–1 million fingerlings a year; large-scale hatcheries sell over 1 million fingerlings a year and also operate grow-out farms.	Commercial hatcheries, both private and public, lack a supply of fingerlings, so they restock the previously harvested fish, which are stunted. Farmers also lack a supply of quality fingerlings, so they either procure mixed-sex or wild tilapia.	Hatcheries are owned by the government, NGOs and private entities. Capacity is 1.4 million catfish and 3.3 million tilapia per year. Most small-scale farmers purchase mixed-sex tilapia seed only once and then raise juveniles harvested from the preceding rearing cycle.	The private sector invests in commercial hatcheries, as it is government policy to divest its farms to the private sector.	They range from intensive private sector small and medium enterprises (SMEs) to large commercial cage culture aqua-farms. Fish seed prices are subsidized by the government.

Characteristics	Egypt	Uganda	Kenya	Cameroon	Nigeria	Ghana
Technology	Sex-reversed all-male fry and fingerlings are raised in warming systems using biogas and hapas covered with a greenhouse system to extend the production season.		Monosex production technology is not popular because of financial constraints to purchase the sex reversal hormone as well as a lack of adequate infrastructure.		Hormone-induced spawning for mud catfish and carps	Production of all-male tilapia fingerlings
Breeding	Genetically selected strain of *O. niloticus* (Abbassa line)	Nile tilapia produced using fish sourced from Ugandan lakes	Genetic improvement of tilapia and *Clarias gariepinus*	Improved line of catfish, *Clarias Gariepinus*, developed by Dutch researchers	Hormone-induced spawning and hybridization of *Heterobranchus bidosalis/longifilis* with *Clarias gariepinus*	Akosombo strain of tilapia developed from fish sourced from Lake Volta
Policy and law, including standardization	Practitioners are required to acquire a health certificate from the General Authority for Veterinary Services and a Certificate of Origin from the GAFRD.	All fish seed producing, supplying and fingerling-raising farms and companies have to be certified under the Fish (Aquaculture) Rules 2003 instrument number 31.	The Fisheries Management and Development Act of 2016 requires acquisition of a license for commercial aquaculture.	No system in place	No system in place	No system in place
Challenges/ constraints	Demand for seed outstrips supply, and climate is seasonal.	Challenges/constraints include inadequate production, non-operational government hatcheries, deficient production technologies and a lack of standardization.		Tilapia are of poor genetic quality because of recycling.	Demand is higher than supply. Wild sources are unreliable, because they are seasonal and usually contain mixed species. Also, hatchery managers lack technical capabilities.	The quality of fish seed available for stocking is poor and erratic. Costs are high for production.

Table 2. Summary of fish seed production and distribution systems in selected African countries.

3. Discussion

3.1. Production of fish seed in Africa

The low production of fingerlings is one of the greatest constraints facing aquaculture expansion on the continent (Brummett 2007; Rothuis et al. 2011; Musyoka and Mutia 2016). Demand for fish seed is far greater than supply in most countries, and various reasons have been identified, among them the poor communication between farmers and seed producers. This has resulted in losses as hatcheries may hold unsold stock while fish farmers who need fingerlings do not know where to find them (Pouomogne and Pemsl 2008). In addition, the quality of seed is poor, with low survival rates and high prices that are unaffordable for peasant farmers. In many cases, small-scale farmers purchase mixed tilapia seed only once and subsequently raise juveniles harvested from the preceding rearing cycle, a practice that causes a serious decline in quality and productivity (Pouomogne and Pemsl 2008).

There are three key considerations in fish seed production: (1) the ability to produce monosex fry, which is preferred for its high feed to weight conversion rate, (2) capacity to produce fingerlings of favorable size at the beginning of the season and, in some instances, (3) the capability to produce fish species that can tolerate higher levels of water salinity (Njiru et al. 2018; Shaalan et al. 2018). In our review, we considered, among other parameters, sources of fish seed, quality of the seed, availability to satisfy demand, technologies used in fish seed production and the different players in the fish seed production sector.

We reviewed 26 studies that examined various aspects of fish seed production in Africa. Most of the studies analyzed all the aspects of fish seed production but at varying depths. All of them reported that the main sources of fingerlings in Africa are wild catches, unregulated spawning in ponds, and government hatcheries. In Egypt, Uganda and Nigeria, which are the leading aquaculture producers on the continent, the private sector is by far the largest producer of fish and fingerlings (Brummett 2007; FAO 2010; Aulanier et al. 2010). To supplement government supply, farmers were permitted to build their own hatcheries for monosex tilapia fry and carp fry. By 2010, there were some 600 hatcheries in operation in Egypt, owned both by the government through the GAFRD and the private sector (FAO 2010). Government-owned hatcheries are still the majority suppliers of fish seed in some countries. In Kenya, for example, the government-owned National Aquaculture Research and Development Training Centre, located in Sagana, supplied about a third of all fry and fingerlings in the country between 2010 and 2016 (Nyonje et al. 2018).

In terms of quantities, large-scale producers largely dominate the fish seed supply chain in most African countries. One study (Satia 2015) reported a unique model from Madagascar, where peasant hatcheries have emerged and successfully maintained good genetic quality. These hatcheries now dominate small-scale aquaculture in the country, supplying rice farmers, who purchase small batches at a time.

Most of the studies reported that local supply in many African countries is collected from natural waters (wild sources). Hatchery production based on controlled spawning is popular among commercial hatcheries (Brummett 2007). Collecting fingerlings from the wild is unreliable, as it is not possible to accurately determine quality metrics such as species and age. Availability is also seasonal. Climate seasonality also affects African countries that are within the temperate zone, such as Egypt and South Africa. Summer temperatures are very suitable for the growth and reproduction of the main farmed species, particularly Nile tilapia. During the winter season, however, temperatures fall below optimal levels for growth and propagation (25°C–30°C) of such varieties (Nasr-Allah et al. 2014).

Most studies reported that the majority of fish farms have accompanying hatcheries. However, most of the hatcheries are either totally abandoned or under-producing because of a lack of technical capabilities among the managers (Brummett 2007). Similar challenges were also reported from Uganda, where farmers risk purchasing poor quality seed because the small-scale hatcheries based in rural areas are limited in technical capacity and resources to produce quality fingerlings (Brummett 2007).

All studies on fish seed production reported that demand for fish seed outstrips supply in most African countries. Three studies (Brummett 2007; George et al. 2010; Adewumi 2015) reported that the deficit is supplemented through imports. Imported fish seed and food fish tend to be cheaper and pose unfair competition to the young aquaculture industry in these countries (Pouomogne and Pemsl 2008). The result is a sustained cycle of fish seed insufficiency.

The lack of technical knowhow is a major impediment to fish seed production in countries such as Nigeria. Most of the studies reported that a major source of losses for farmers is poor management of broodstock, especially feeding and handling, coupled with poor record-keeping of all activities regarding induced spawning, care of eggs, fry, feeding and general management of fingerlings. The majority of small-scale farmers, lacking technical knowhow and access, purchase mixed-sex tilapia and/or raise juveniles harvested from the preceding rearing cycle, causing a decline in stock and low pond productivity (Pouomogne and Pemsl 2008; Adewumi 2015). The resulting decline in stock quality from this practice is one of the causes of low pond productivity.

3.2. Marketing and distribution channels

We reviewed 16 studies that analyzed various aspects of fish seed marketing and distribution in Africa. Most of the studies reported that marketing and distribution on the continent are largely unorganized. In some formal markets, buyers place orders with hatcheries. The norm, however, is that buyers "simply show up to buy fish." This lack of organization is a key source of losses for farms, as fingerling supply and demand need accurate synchronization (Brummett 2007). For instance, if buyers are unavailable when needed, catfish fingerlings will cannibalize each other, while tilapia will go on to reach precocious sexual maturity, making them useless for commercial farming.

Of the 16 studies reviewed, 12 reported findings on transportation of fish seed. Handling during transportation is a real challenge in the value chain. Unsuitable packing and transportation were reported to cause high mortality rates. One bright spot is Uganda, where the design and layout of ponds include a wide enough wall to allow access by vehicles for easy loading and transportation of fingerlings, resulting in reduced stress and mortality (Aulanier et al. 2010).

Ten of the studies reported on the efficiency of the distribution channels. All the studies found inefficiencies in the value chain, including lack of information and planning. Information flow is one of the most important components of an efficient product marketing and distribution system (Patnayakuni et al. 2006). Many African fish seed systems have poor communication/information flows between seed producers and fish farmers (Pouomogne and Pemsl 2008). As a result, fish farmers do not know where to find fingerlings when they need them, even though hatcheries may hold unsold stock. In countries such as Cameroon, where wild catches are popular, fingerling collectors collect fingerlings over a 4-month collecting season that runs from December to March, and supply to local buyers immediately (Pouomogne and Pemsl 2008). Most of the collectors lack the skills and infrastructure to keep the juvenile fish alive to sell them outside the collecting season.

One study (Brummett 2007) reported innovative distribution models being adopted in some countries in Sub-Saharan Africa. In Uganda, specifically, the SUNGENOR hatchery, which specializes in improved tilapia seed from the GIFT strain of Nile tilapia, implements an outgrower model. The model involves the company supplying seed to contracted farmers, who sell the fish back to NGEGE Ltd, which is SUNGENOR's fish processing and export partner (Brummett 2007). Such outgrower models resulted in better synchronization of demand and supply, reducing losses from overproduction of fish seed. In Egypt, where strong climate seasonality has exacerbated the problem of synchronization, hatcheries are forced to use expensive technology to get fingerlings ready for sale in early spring, when the weather warms up (Brummett 2007).

Of the 16 studies, 12 reported the channels and markets where fish seed is sold. Depending on the varieties and seasons, fish seed is either sold locally or exported. One study (Aulanier et al. 2010) reported that hatcheries in Uganda have been exporting fry to Kenya, where demand for sex-reversed male tilapia fry increased following implementation of the Fish Farming Enterprise Productivity Program by the government of Kenya.

3.3. Research, technology and innovation

Research on improved strains and species of fish is going on in various parts of Africa. We reviewed 26 studies that identified different kinds of research and innovations in breeding, new fish strains and species, and technologies in infrastructure and input production. However, adoption of the technologies has been generally slow. One study (Brummett et al. 2008) identified concerns of biodiversity as the main reason why. On the contrary, another study (Pouomogne and Pemsl 2008) identified excessive wild collection of juveniles as a threat to the sustainability of capture fisheries in the fishing areas.

Development is ongoing on the production of all-male tilapia fingerlings and spawning of *Clarias* in large numbers using injections of fresh pituitary followed by hand stripping (Pouomogne and Pemsl 2008; Satia 2015). These practices have increased productivity and seed value. In Ghana, fish seed from the Akosombo strain of tilapia, which provides a 30% improvement in growth, are now widely adopted and distributed to government hatcheries, while the Fisheries Centre in Kajjansi in Uganda has bred eight strains of Nile tilapia from fish sourced from lakes Victoria, Albert and Kyoga. In Kenya's Sagana area, genetic improvement programs for tilapia and *Clarias* are ongoing (Satia 2015).

In Nigeria, species such as mud catfish and carp are subjected to hormone-induced spawning (Brummett 2007). Relevant skills for such advanced breeding are transferred to interested practitioners through government and donor-sponsored short courses in fish seed multiplication around the country. The situation is similar in Cameroon, where research arrangements in partnership with organizations such as the Institute of Agricultural Research for Development, WorldFish and FAO are providing technical and skills support (Pouomogne and Pemsl 2008). Adoption of new technologies such as intensive recirculating and flow-through fish production systems has considerably increased the volume of production of both fish seed and fish (Brummett 2007). As a result, fish seed production in Nigeria jumped 10-fold from 3 million in 2000 to about 30 million in 2005.

3.4. The role of the government

The government plays different roles in fish seed systems. The commonly reported ones in our review included developing the legal and policy systems, developing and enforcing standards, and being an investor in the fish seed value chain. We reviewed 20 studies that reported some aspects of the government's role in the fish seed systems.

Although now mainly operated by the private sector, the growth of the fish seed sector owes its origins to initial funding and support from the public sector and donors. We reviewed 17 studies that reported government funding and investment in the sector. In Uganda, for instance, the first large-scale hatchery was by a public agency, the Kijjansi Aquaculture Research and Development Centre. The center operated as the only large-scale fingerling producer before other larger private investments came up in response to the growing demand for quality fish seed (Brummett 2007). In Egypt, the GAFRD was the first agency to set up hatcheries (Nasr-Allah et al. 2014) before legislation allowed private agencies and farmers to set up and operate private ones. To date, the GAFRD operates several hatcheries in Egypt (FAO 2010; Shaalan et al. 2018).

Although effective in unlocking capital constraints and creating demand, most of the studies reviewed reported that government-operated fish seed production systems have proven ineffective and inefficient in most African countries. In Cameroon, for example, less than five of the 32 public stations have survived. Production from the surviving stations is highly erratic because of sporadic funding and poor management (Pouomogne and Pemsl 2008). In response to government inefficiency and the growing demand for fish seed, private hatcheries developed by the private sector (firms, common interest groups, and farmers) have evolved to fill the gap (Brummett 2007; Pouomogne and Pemsl 2008). Although private hatcheries are quickly coming up in Africa, they are still not able to satisfy the demand for fish seed, so farmers are forced to source from alternative sources, such as wild catches or imports.

The production of fingerlings in Egypt is mainly controlled by the GAFRD to prevent malpractice. The GAFRD monitors and regulates the transportation of fry and fingerlings between hatcheries and aquaculture farms (FAO 2010; Shaalan et al. 2018), but some of these regulations have proven to be barriers rather than facilitators of the sector. In Zimbabwe, for example, farms that produce tilapia seed can only move their products out of the Zambezi Valley, including Lake Kariba, with a permit from the government's Parks and Wildlife Authority, which is very difficult to get.

The role of the government in setting standards and quality guidelines for the fish seed market is indispensable but has not been implemented successfully in Africa. We reviewed 13 studies that identified the government's role in setting standards and guidelines for fish seed production. In Nigeria, for example, there exists no system of quality control in fish seed production practices or standardization of fingerling size and pricing (Adewumi 2015). Consequently, seed producers sell different sizes of fry and fingerlings, with neither standardization nor guarantee on the quality, leading to exploitation of buyers and heavy post-stocking mortalities (Adewumi 2015). Even in countries such as Uganda, where a legal and institutional framework to enforce standards is in place, enforcement is very weak (Aulanier et al. 2010). As a result, the few hatcheries/farms that claim to supply monosex tilapia, supply fingerlings of which only a variable percentage is male (Aulanier et al. 2010).

One unexplored option in Africa is the public-private partnership (PPP) model, which is rapidly being adopted in other sectors across the continent (Bernadine et al. 2016). We reviewed one study (Adewumi 2015) that identified a PPP model in Nigeria between the Lagos State government and a Finland-based firm to set up a fish feed plant. The PPP model can unlock challenges facing public hatcheries by providing them with access to the technical capacity of the private sector, while the private sector can access the public infrastructure already in place. Such an arrangement is a win-win for the government and the private sector and can unlock the huge production potential in Africa.

3.5. Comparative analysis of seed systems between Africa and Asia

In this section, we undertake a comparative analysis of fish seed systems in Africa versus Asia. Scarcity of fish seed has been identified as a key constraint to aquaculture development in almost all countries in Africa, but it has only been identified in two countries in Asia (Indonesia and Vietnam) (Hishamunda et al. 2009). The purpose of the comparative analysis, therefore, is to benchmark selected parameters in Africa's fish seed systems against those in Asia and recommend possible interventions for improvement. We reviewed 10 studies that reported on various aspects of fish seed systems in countries in Asia. Three of the aspects are discussed in sections 3.5.1–3.5.3.

3.5.1. The role of governments

In Africa, the government still plays a key role in developing and managing hatcheries and aquaculture stations. Several hatcheries have been set up through government and donor funding. Most are still operating, albeit quite inefficiently (Brummett 2008; Pouomogne and Pemsl 2008). The greater role that the government plays in the production of fish seed is a major contributing factor to the low pond productivity experienced in Africa. Most public hatcheries suffer from mismanagement and inadequate funding. In addition, public hatcheries are a source of unfair competition to private operators who attempt to set up hatcheries (Pouomogne and Pemsl 2008; Aulanier et al. 2010).

Fish seed systems in Asia started the same way as in Africa, with the government playing a major role in setting up the first hatcheries. As the private sector emerged and took over, public hatcheries now mainly provide fry to smallholders, stock public waterways or focus on raising indigenous freshwater species, products that are mainly not attractive to the private sector (Hishamunda et al. 2009). The fish seed production systems in Asia are largely private sector driven, with the government undertaking a regulatory and standardization role (Shikuku et al. 2021). Even where governments are more proactive, such as in Indonesia, Malaysia, Thailand and, particularly, Vietnam, their role is restricted to providing incentives and other supporting policies (Hishamunda et al. 2009). A notable exception is in the Philippines, where the government is funding support for carp and the production of seed in the milkfish industry (Hishamunda et al. 2009).

3.5.2. Market organizations

Relative to Asia, the fish seed market in Sub-Saharan Africa is generally unorganized. There is little organized marketing, and producers either place orders with hatcheries and have them delivered if the orders are large enough or just visit hatcheries to buy fingerlings (Brummett 2008). This sort of system where demand and supply are not synchronized makes planning difficult for hatcheries. The implication is that hatcheries could overproduce when demand is low or vice versa, leading to losses. In Asia, large numbers of middlemen buy from hatcheries and sell to grow-out farms (Brummett 2008). The markets are also connected, and traders and farmers regularly and easily import fish seed from neighboring countries when prices are lower. For example, farmers in Vietnam import grouper (and seabass) broodstock from Taiwan (Hishamunda et al. 2009).

3.5.3. Production systems

In terms of production infrastructure and scale, hatchery systems employed in most African countries are typically small-scale, producing mainly tilapia fingerlings in small open ponds, Egypt being the only exception. Advanced production techniques such as hormone sex reversal to produce only male populations are not yet popular due to financial constraints, especially with small-scale producers (Nyonje et al. 2018).

Wild captures are still very popular in many African countries (Pouomogne and Pemsl 2008; Aulanier et al. 2010). Most farmers purchase fingerlings that are caught from the wild, lakes and dams, scooping fry from shallow waters or removing young fry from their mother's mouth (Brummett 2007; Nyonje et al. 2018). Because of the relatively lower price and poor development of hatcheries, capture fisheries are still an important source of broodstock in some Asian countries, especially for the culture of some marine and brackish water finfish species (Hishamunda et al. 2009; Komarudin et al. 2010; Fachry et al. 2018). In Vietnam, for example, seed shortage has hindered aquaculture expansion, leading to dependence on the wild to supplement imports from Taiwan (Hishamunda et al. 2009). The seed shortage has led to understocking cages, resulting in low cage and farm productivity and profitability (Hishamunda et al. 2009).

Brummett (2007) reports that, except for Egypt, the cost of fish seed production is generally high in Africa because of low-intensity systems. In Egypt, like most Asian countries, hatcheries practice industrial-scale hatcheries in indoor breeding tanks to accelerate spawning in early spring, while water tanks are warmed using boilers and biogas during winter. The average size of the hatcheries is 1.33 ha, with an average production of 8 million seeds. Some hatcheries in Egypt attain a production intensity of 9.45 million seeds per ha, which makes them highly intensive and high-yielding (Nasr-Allah et al. 2020). Most hatcheries in Asia have also shifted to hybrid strains in response to demand from fish farmers. Fish farmers prefer hybrid varieties because of the faster growth of hybrid groupers in comparison with the parental stocks (Sugama et al. 2014) and perceived resistance to disease (Fachry et al. 2018).

Production of high quality fingerlings in Zambia.

4. Conclusion and policy recommendations

Aquaculture production in Sub-Saharan Africa has consistently performed poorly despite the huge capital investment by governments and donors. Beyond Sub-Saharan Africa, only Egypt has a globally competitive aquaculture sector in Africa. Unavailability of quality fish seed is a major constraint facing aquaculture in Africa. Fish seed supply on the continent is erratic and unreliable, and it is unable to supply seed of the right quality and quantity when farmers need them. Yet despite the poor performance of the seed sector, fish seed systems in Africa are poorly documented, and the literature on them is hardly sufficient. The objective of this systematic review, therefore, was to synthesize the available evidence on these systems in Africa.

Our review identified various challenges facing the continent's fish seed sector. First, the tendency to channel government funding into setting up public hatcheries and/or aquaculture stations is evidently ineffective. Most government-run hatcheries are inefficient, plagued by poor management and a lack of funding, and become dysfunctional after a short while. Unfortunately, governments have focused on funding at the expense of the key role they play in putting in place standards and quality guidelines for the fish seed market. Where such standards exist, enforcement is weak or nonexistent. Consequently, farmers are cheated and incur losses from buying poor quality fry and fingerlings.

Furthermore, most fish farmers in Africa do not have access to improved species and/or strains that are available in other regions. Despite the obvious benefits of genetic improvement and improved breeding, the aquaculture sector in Africa has shunned these new technologies because of, among other reasons, concerns for biodiversity.

Other key constraints facing fish seed production include the lack of market organization and poorly developed supply channels. Market organization is key for fish seed supply, which requires accurate synchronization with demand. Consequently, hatcheries face planning difficulties, leading to losses from overproduction when demand is low or vice versa.

The study recommends policies that promote using improved breeds and strains of fish seed to improve productivity, while at the same time protecting biodiversity and the environment. In addition, governments should develop guidelines and standards for producing quality fish seed. Furthermore, institutional mechanisms to enforce the standards and guidelines should be put in place.

Photo credit: Heba El Begawi/WorldFish

Harvesting tilapia fry from a hapa in Egypt.

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We have a global presence across 20 countries in Asia, Africa and the Pacific with 460 staff of 30 nationalities deployed where the greatest sustainable development challenges can be addressed through holistic aquatic food systems solutions.

Our research and innovation work spans climate change, food security and nutrition, sustainable fisheries and aquaculture, the blue economy and ocean governance, One Health, genetics and AgriTech, and it integrates evidence and perspectives on gender, youth and social inclusion. Our approach empowers people for change over the long term: research excellence and engagement with national and international partners are at the heart of our efforts to set new agendas, build capacities and support better decision-making on the critical issues of our times.

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