frontiers | Frontiers in Sustainable Food Systems

TYPE Systematic Review
PUBLISHED 02 August 2023
DOI 10.3389/fsufs.2023.1208918

OPEN ACCESS

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RECEIVED 19 April 2023
ACCEPTED 17 July 2023
PUBLISHED 02 August 2023

CITATION
Munguti JM, Obiero KO, Iteba JO, Kirimi JG, Kyule DN, Orina PS, Githukia CM, Outa N, Ogello EO, Mboya JB, Ouko KO, Liti D, Yossa R and Tanga CM (2023) Role of multilateral development organizations, public and private investments in aquaculture subsector in Kenya.
Front. Sustain. Food Syst. 7:1208918.
doi: 10.3389/fsufs.2023.1208918

Role of multilateral development organizations, public and private investments in aquaculture subsector in Kenya

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Rapid population and economic growth, increased health benefits of aquatic food, and changes in lifestyles and preferences as a result of rapid urbanization and globalization are all contributing to the rapid growth of aquaculture production in Kenya. Despite significant investment efforts from the national and devolved governments as well as donors and international organizations, smallholder aquaculture production is yet to result in a significant increase in incomes and improved food and nutrition security. We conducted a scoping review to investigate the roles of multilateral development organizations, international financial institutions, and public and private investments in Kenya's aquaculture subsector. We draw on lessons learned from previous projects implemented at the national, county, and farm levels to make recommendations for sustainable aquaculture intensification in Kenya. To unlock Kenya's aquaculture potential and improve its food and nutrition status, deliberate efforts must be made to create a conducive environment for public and private investment in the industry. First, there is a need to coordinate and clearly articulate the roles and responsibilities among devolved and national governments, donors, and financial institutions through public-private partnerships to ensure optimal allocation of financial, human, and infrastructure resources. Second, more collaborative research should be devoted to the design and construction of climate smart culture systems, developing new species to guarantee supply of high-quality products; developing and scaling low-cost and highly nutritious fish feeds based on novel ingredients; and enhancing resilient livelihoods through innovative aquaculture practices and market linkages to create employment opportunities for youth and women. Finally, the national and devolved governments should create an enabling policy environment through tax incentives and regulatory reforms to combat climate change, protect nature and biodiversity, sustain livelihoods, and mainstream food and nutrition initiatives into the design and implementation of future aquaculture projects.

KEYWORDS

aquaculture, role, multilateral donors, public, private, investments, Kenya

1. Introduction

More than 800 million people depend on fish and other aquatic foods and fish also contribute 20% of the global animal protein consumed by 3.3 billion people (FAO, 2022). According to Bush and Oosterveer (2019), aquaculture presently produces more than half of the fish consumed directly by humans and is projected to increase to 140 million tonnes by 2050 (FAO, 2018). Aquaculture generated US$264 billion in revenue in 2018 (WorldFish, 2020). Aquatic foods directly contribute US$24 billion to the African economy, as well as food and nutrition security (WorldFish, 2020). The need for fish as a food source is expected to increase as the world's population rises to 9.7 billion by 2050, placing further strain on the world's fisheries (United Nations, 2015). As a result of the ongoing and impressive development in the availability of fish for human consumption, aquaculture is progressively garnering attention as a solution to this shortage (FAO, 2022; Le Gouvello et al., 2022).

Fish and other aquatic foods have an array of roles in the food systems of Africa, including generating revenue and serving as a vital source of micronutrients, especially for women and young children (Chan et al., 2019; Tran et al., 2019). However, the value of fish and aquatic foods in Africa are often overlooked in development research, policy, and investment cycles (Chan et al., 2021). Indeed, the vital contribution of fish to food and nutrition security has largely been overlooked in high-level food policy dialogs and associated funding portfolios of major international organizations and actors (Bennett et al., 2021). For instance, between 1968 and 2018, World Bank investment in capture fisheries and aquaculture accounted for an average of 1.8% of all agricultural funding; although funding has increased to an average of 2.6% (and as high as 5.4% in 2018) over the past decade (Bennett et al., 2021).

Sustainable financing and investment are required to sustain capture fisheries and promote aquaculture expansion in Sub-Saharan Africa to shift the aquatic food chain towards healthier diets (Chan et al., 2021). Over the past decade, there has been increased investments aimed at intensifying culture systems and commercializing the aquaculture value chain on the continent (Kaminski et al., 2018; Chan et al., 2019). Despite its rich aquatic and biological diversity, the continent contributes less than 2.5% of total global aquaculture production (Satia, 2017; Obiero et al., 2019a). Many governments, donors and international organizations have spearheaded aquaculture development in Africa, primarily targeting smallholder farmers to increase food and nutrition security (Brummett et al., 2008; Kaminski et al., 2018). In addition, international financial institutions have made significant contributions to aquaculture development, particularly through human and institutional capacity building, funding applied and adaptive research, developing codes of practice, and provision of capital for investment in the production value chain (World Bank, 2007). Given that Africa's population is expected to more than double by 2050 and that an estimated 278 million people suffer from chronic hunger (FAO, IFAD, UNICEF, WFP and WHO, 2022), aquaculture is projected to play a significant role in providing critical animal protein foods to millions of people struggling to maintain decent livelihoods (Kobayashi et al., 2015; Golden et al., 2017).

Aquaculture has become well-integrated into the global food system over the past two decades (Verdegem et al., 2023). Since 2000, annual production has increased rapidly due to the expansion of production areas (Oyinlola et al., 2018), intensification of production systems (Verdegem et al., 2023), improved production management, and the adoption of new and improved technologies and innovations (Kumar and Engle, 2016; Henriksson et al., 2018). In recent years, more attention is focused on integration of aquaculture systems into local nutrition-sensitive, circular economy, and sustainable food systems. African countries should effectively harness the potential of aquaculture to meet increasing demand for fish while reducing poverty and stimulating economic growth by prioritizing investments in research, development, infrastructure, and capacity-building initiatives (Adeleke et al., 2020).

In Kenya, inland fisheries and aquaculture represent a vast potential to support local economic development in terms of fighting poverty, reduction of food insecurity and the generation of employment in Kenya (Schubert et al., 2021). Kenya's Vision 2030 development blueprint recognized fisheries and aquaculture subsector as a source of food security, poverty alleviation, and employment creation. The country has abundant inland and marine resources suitable for scaling up fisheries and aquaculture production and blue economy related industries and services to spur inclusive economic growth and development (Obiero et al., 2022). Kenya's fisheries and aquaculture sector contributes approximately 0.7% to country's gross domestic product (GDP). The sector supports about 1.5 million people directly and indirectly working as fishers, traders, processors, suppliers and merchants of fishing accessories and their dependents (GoK, 2022). The country's total fish production from capture fisheries and aquaculture was 174,000 tonnes, valued at KES 37.5 billion in 2022 (KNBS, 2023). The fisheries sector is over-reliant on wild catch, whose volumes are declining due to overfishing, biodiversity loss and pollution, especially in the territorial waters. As a result, the sector cannot meet the annual demand for fish in Kenya, currently estimated at 550,000 to 600,000 tonnes against a production base of 180,000 to 240,000 tonnes (Obiero et al., 2019b). There is a significant gap between projected demand and national fish production, which is partially offset by fish imports. Kenya's *per capita* fish consumption has stagnated at around 4.5 kg/person/year, compared to a global average of 21 kg/person/year. The country aims to increase *per capita* fish consumption to 10 kg per person per year by 2030, which would necessitate greater production, particularly through intensive and semi-intensive aquaculture systems (Obiero et al., 2019b).

Aquaculture production in Kenya has almost doubled over the past decade, resulting in increased income and employment opportunities, improved nutritional status among vulnerable communities and regional development in rural areas (Cheserek et al., 2022). Aquaculture production increased from 12,152 tonnes in 2010 to 22,140 tonnes in 2022, accounting for 12.7% of the country's total fish output (Figure 1). This growth was primarily due to the implementation of the Fish Farming Enterprise Productivity Project (FFEPP) under the Economic Stimulus Program (ESP) in which the Kenya Government allocated KES 3.986 billion in two phases for pond construction, supply of fingerlings and stocking of ponds, acquisition and supply of fish farming inputs and specialized equipment as well as capacity building and extension support services (Musa et al., 2012;

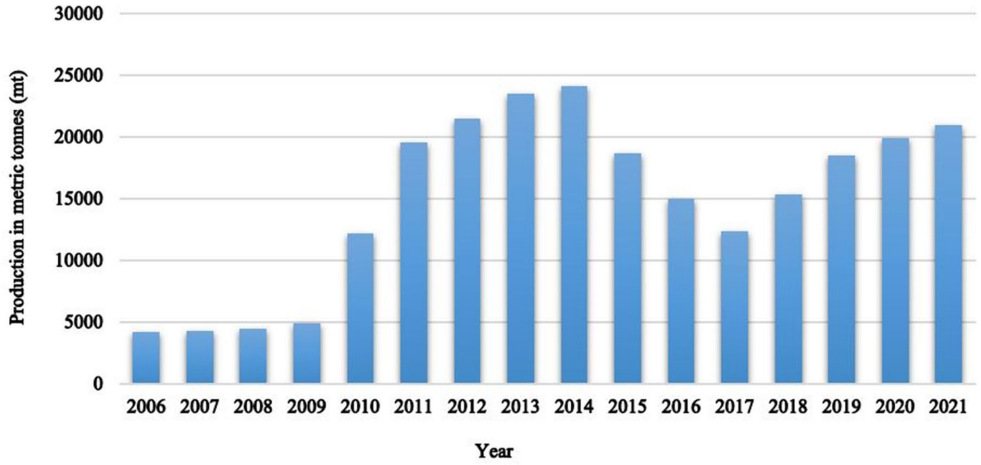

FIGURE 1
Trends in aquaculture production in Kenya from 2006 to 2021 (KNBS, 2022).

Munguti et al., 2021). The ESP was a massive high impact fish farming intervention that invested heavily in projects with both short-term and long-term benefits, and there are strong indications that aquaculture production will continue to grow rapidly, driven by the commercially oriented large-scale sector. In this regard, small-scale aquaculture producers should be organized into viable enterprises capable of realizing economies of scale and forging economic ties with input suppliers, product markets, technical service providers, and financial service providers.

Smallholder aquaculture production in Kenya has mostly remained stagnant, despite significant efforts from public and private sector institutions and actors at all nodes of the aquaculture value chain (Munguti et al., 2014). Previous aquaculture development initiatives have resulted in slow growth due to inadequate quality seed and feed, low uptake of appropriate technologies, poor market linkages, poor management of culture systems, heavy reliance on weak government extension and advisory services, low technical capacity in disease diagnostics and biosecurity, and importation of cheaper fish products (Ngugi and Manyala, 2009; Obiero et al., 2019c). Additionally, although existing universities and mid-level colleges offer fisheries and aquaculture degrees, current curricula and the aquaculture training landscape do not adequately address core skills and competencies, resulting in graduates who are not sufficiently skilled for the aquaculture job market and business, frequently exacerbated by inadequate financial and physical infrastructure in universities and technical vocational training centers (Nyonje et al., 2021). There is need to understand the multifaceted challenges in aquaculture development in Kenya in order to provide more context-specific solutions to address both opportunities and challenges for future development.

In this article, we review and synthesize existing literature to document the roles of multilateral development organizations, international financial institutions, public and private sector investments in the aquaculture subsector in Kenya. The goal is to provide lessons and recommendations for the design and implementation of future fisheries and aquaculture projects in the country by the relevant stakeholders in the sectors including policy and decision makers, private sector actors, academicians, and researchers in low-and middle-income countries, development organizations, input suppliers, farmers, processors, traders, and consumers.

2. Methodology

The present study adopted a scoping review methodology (Arksey and O'Malley, 2005; Levac et al., 2010) to conduct a comprehensive literature review on the involvement of international organizations, institutions from the public and private sectors, and actors in Kenya's aquaculture subsector. According to Arksey and O'Malley (2005), scoping studies *"aim to map rapidly the key concepts underpinning a research area and the main sources and types of evidence available."* Levac et al. (2010) expanded on Arksey and O'Malley (2005) methodological framework and made recommendations to improve consistency in conducting and reporting scoping studies.

As a starting point, we applied the Preferred Reporting Items for Systematic Reviews and Meta-Analyzes extension for Scoping Reviews (PRISMA-ScR) checklist to map relevant literature (Tricco et al., 2018). The steps were as follows: (1) identify relevant studies, (2) screen and select relevant publications, (3) chart the data and information, and (4) assemble, summarize, and report the results. Figure 2 illustrates the steps of the scoping review. To achieve the intended objectives, we used a set of keywords (related to aquaculture, development partners, national government, county governments and the private sector) to search scientific databases of Research Gate, Google Scholar, and The Lens to find published research articles, review papers, technical reports, books, book chapters, and dissertations/thesis. The literature review was conducted between January and February 2023.

We also searched for published material from international institutions that are directly and indirectly involved in aquaculture, e.g., FAO and WorldFish. The search terms used were "international donors," "aquaculture," "government," "public sector," "private sector," and "Kenya." Boolean operators ("OR," "AND," and "NOT") were appropriately used in databases and search engines to narrow down

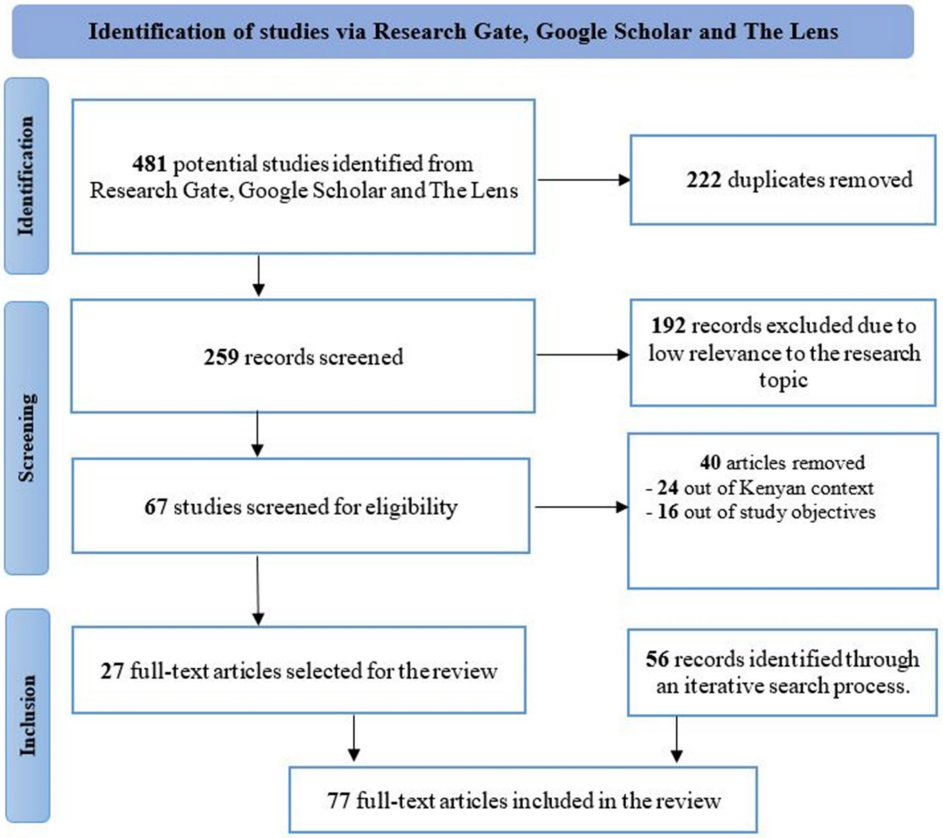

FIGURE 2
Flow chart of the selection process of studies examining the role of international organizations, public and private sector in aquaculture development in Kenya.

and refine the search. We used a five criteria checklist to include publications for literature review. Specifically, the publications were to (1) be topically relevant and focused on aquaculture, (2) meet academic quality, i.e., only scientific, technical, and academic documents were accepted, (3) be published in the last 12 years (2010 to 2022), (4) be written in English language, and (5) focus on geographic location of Kenya and its 47 counties.

The search approach yielded 481 publications including 167 works in Research Gate, 123 works in Google Scholar, and 191 works in The Lens. To reduce reporting bias, the full-text and abstract of each article were reviewed by at least two reviewers in accordance with suggested protocols for scoping reviews (Peters et al., 2015). After eliminating duplicates, 259 distinct works remained. Following a screening of the primary title and abstract, 67 articles were included as potentially relevant. After reading the full-text articles, 27 publications met the criterion for inclusion in this current review. Further, fifty-six (56) records were included in this review after a three-step iterative search process that involved (1) reviewing available literature, and selecting relevant articles to include in the search data, (2) evaluating the presented data and determining its relevance to the research goals, and (3) identifying knowledge gaps to inform future research needs (Figure 3). The relevant studies were then imported into the Mendeley® literature management software. Microsoft Excel was used to develop a data-charting form for analysis.

3. Results and discussion

3.1. Evolution of aquaculture in Kenya

According to Obwanga et al. (2020), the growth of aquaculture in Kenya is categorized into three development phases, i.e., introduction phase, public and donor supported phase, and private sector-investment phase as described in Table 1.

3.1.1. Introductory phase

Aquaculture was introduced in Kenya by the colonial government for sport fishing in 1920s (van Someren, 1960). The first fish introduced into static water pond culture were native tilapias, which were later followed by common carp and African catfish. Between 1940s and 1960s, aquaculture was promoted as sustainable aquatic production system to improve rural nutrition, wealth creation, diversify agriculture failure risks, and create jobs in rural areas (Adeleke et al., 2020). The initial efforts focused on fundamental research and development to produce appropriate technologies for culture of indigenous species (Brummett et al., 2008). The colonial administration set up the Sagana Fish Farm for warm-water species, i.e., tilapia and catfish and Kiganjo Trout Farm for cold-water species in 1948 to produce seed for stocking ponds, dams, and rivers (MoFD, 2010).

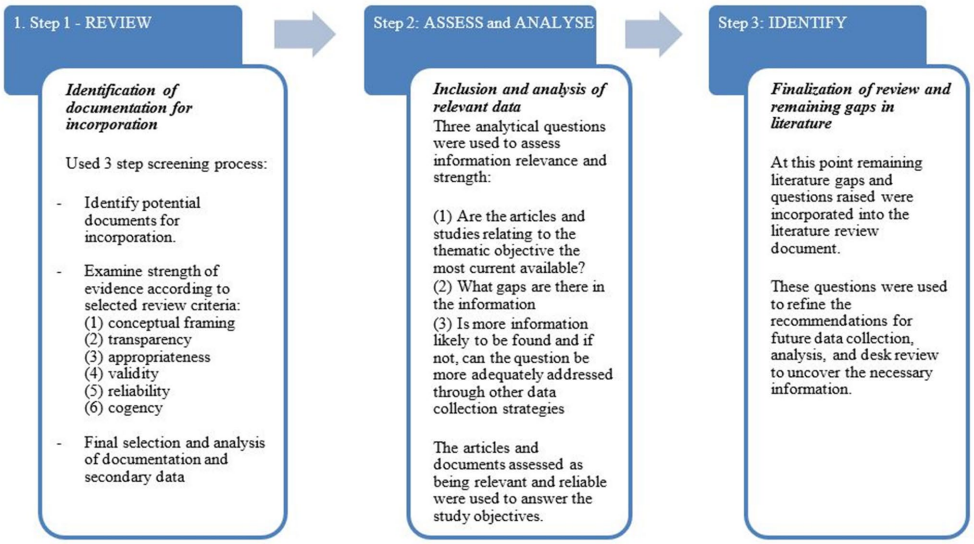

FIGURE 3
The iterative process utilized to conduct literature review.

3.1.2. Public funding and donor supported phase (1960 to 2010s)

Following Kenya's independence, the newly formed government established the Fisheries Department domiciled in the Ministry of Agriculture to spearhead fisheries development in the country. The Fisheries Department promoted the fledgling industry through "Eat More Fish Campaigns" resulting in the rapid development of rural pond fish farming in Kenya, mainly in the Lake Victoria region. Thus, by the early 1970s, Western and Nyanza Provinces had an estimated 30,000 ponds (Zonneveld, 1983). However, because the majority of the ponds were small, most of them were eventually abandoned (Kagai, 1975). This resulted in a rapid decrease in fish ponds in the region, owing to poor yields, inadequate high quality fingerlings and feeds, and limited technical know-how in fish farming husbandry (Okemwa and Getabu, 1996). According to Ngugi and Manyala (2009), there were 10,000 existing ponds in 1989, with approximately 5,000 actively managed based on a review of 28 District fisheries offices annual reports. In the late 1970s, Ngomeni Prawn Farm was established as a pilot project, marking the beginning of mariculture in the coastal region (Rothuis et al., 2011). Food security, poverty eradicating, and job creation in rural areas were the top priorities for donors and policymakers. Even with technical and financial support from numerous international and bilateral donors, as well as government provision of seed and extension services, subsistence fish farming in ponds dominated the subsector (Okemwa and Getabu, 1996). According to the national development plan for the industry developed in 1982, aquaculture was expected to produce 44,500 metric tonnes annually by 1990, or roughly 20% of the total fish production (GoK, 1982). However, by that time, aquaculture output was only 975 tonnes by 1990, far short of the target. Between 1970 and 2006, aquaculture production oscillated between 1,000–4,000 MT. In 2004, there were approximately 7,500 small-scale fish farmers producing fish from 10,371 ponds with a combined surface area of 168 hectares. Due to the low fish harvests and poor economic returns on and capital investments, many farmers regarded aquaculture as a risky business. In 2007, about 4,250 metric tonnes of fish was produced by 4,742 farmers from 7,477 ponds covering a surface area of 217 hectares (ha), 301 dams and reservoirs (497 ha), and 248 tanks and raceways countrywide (Nyandat and Owiti, 2013).

Between 2009 and 2013, the Kenya Government implemented the large-scale Fish Farming Enterprise Productivity Project under the ESP to promote smallholder aquaculture production through targeted assistance for input provision, farmed fish production, post-harvest handling technologies, and related activities (Ole-Moiyoi, 2017). In 2012, during the peak of the subsidy program, the number of smallholder farmers increased to 49,050 owning approximately 69,998 ponds occupying 2,063 Ha (Nyandat and Owiti, 2013). Furthermore, during the FFEPP implementation phase, a mapping of suitable aquaculture locations was carried out guided by water availability, climatic conditions, soil type, terrain, land use, and access to inputs and markets. The Western, Central, and Eastern parts of Kenya were reported as the most suitable areas for fish farming. As a result, some 9.58 million ha were identified as areas of high suitability, 40.56 million ha with medium suitability and 3.24 million ha with low suitability, especially in arid and semi-arid (ASAL) regions (Ogello and Munguti, 2016). The suitable regions are, however, at risk of climate change (Munguti et al., 2022b). The regions in Western Kenya are threatened by frequent heavy rainfall, which increases the risk of flooding of Lake Victoria, while the Central/Eastern area is under threat of drought, which makes pond farmers rely more heavily on natural water points.

3.1.3. Private sector led aquaculture development

Public-private producers' partnerships have been promoted as the best option for aquaculture growth in Kenya. This is due to an appropriate distribution of risks among the parties in these partnerships, which are funded by both the government and donors. Currently, several private investment organizations have been

TABLE 1 Historical phases of aquaculture development in Kenya.

Phase	Period	Description of activities
I – Introductory Phase	1900–1950s	• Introduction of fish farming by stocking trout in rivers for sport fishing by colonialist between 1910 and 1921
		• Basic research and development (R&D) to provide practical technologies for culture of indigenous species
		• In 1948, the colonial government established Sagana and Kigango fish station for culture of catfish, tilapia, and trout
II – Government and donor support phase	1960–2010	• At independence, the new government established the Fisheries Department (FD) domiciled in Ministry of Agriculture
		• The FD popularized fish farming through "Eat More Fish Campaigns"
		• By early 1970s, there was a rapid spread of rural pond fish farming in Kenya (>30,000 fishponds) in Nyanza and Western Kenya
		• Between 1970–2006, aquaculture production oscillated between 1,000–4,250 tonnes.
		• Introduction of mariculture in 1980s with the establishment of the Ngomeni Prawn culture pilot project along the coastal region
		• The FAOIUNDP, in 1966, the World Bank in 1978, NORAD during 1970–1988, EEC - during 1984–1986, the Government of Belgium in 1984, USAID during 1983–1990 and IFS in 1974 have aided projects on aquaculture research and development
		• The 2010 Constitution established a devolved system of governance with most agriculture functions transferred to County Governments
		• During the 2009/2010 financial year, the Kenyan Government through the Economic Stimulus Program (ESP) launched the Fish Farming Enterprise Productivity Program (FFEPP) in 2009, with an initial budget of KES 2.2 billion (Charo-Karisa and Gichuri, 2010; Musyoka and Mutia 2016)
III – Donor supported projects and private sector led ventures	2010 – Present	• Establishment of cage culture in Lake Victoria and other reservoirs
		• The Third Medium Term Plan (MTP III) 2018–2022 of Vision 2030 identifies the Blue Economy (including the fisheries and aquaculture sector) as one of the priority areas with high potential to spur inclusive economic growth and development in Kenya
		• Substantial donor funding for aquaculture development, e.g., USD 143.3 million Aquaculture Business Development Program (ABDP) funded by IFAD from 2018–2026 and Kenya Marine Fisheries and Socio-Economic Development (KEMSFED) Project worth KSH 10 billion supported by the World Bank from 2020–2025
		• Private sector support by the Dutch Government to explore business opportunities in aquaculture. The Dutch supported initiatives include FoodTechAfrica, Kenya Market Led Aquaculture Program (KMAP), IDH-Sustainable Trade Initiative and Lattice Aquaculture that have brought a consortium of partners to tackle different challenges facing smallholder producers
		• Gatsby Foundation, through Msingi East Africa identified aquaculture as a high potential sector to develop. Farm Africa also supported Aqua Shops Project, funded by DFID

established to tackle different challenges facing smallholder producers (Table 2; IDH, 2023).

3.2. Aquaculture production trends

Aquaculture in Kenya is viewed as a viable option for closing the growing gap between fish demand and its supply (Obiero et al., 2019b). Freshwater fish account for over 75% of Kenya's reported aquaculture production. Nile tilapia (75%) and African catfish (18%) make up the majority of aquaculture production while common carp (6%) and rainbow trout (1%) are two exotic cold-water species practiced in limited scope (Opiyo et al., 2018; Munguti et al., 2022a). Small scale pond farmers owning 1–2 ponds dominates fish farming in Kenya. However, small-scale farmers are not producing volumes presented in government projected statistics. In 2021, aquaculture production was 21,076 metric tonnes with a farm gate value of KES 6.714 billion compared to 19,945 metric tons valued at KES 6.303 billion in 2020 (GoK, 2022). In 2022, pond-based production was projected to reach 23,000 tonnes from 55,032 fish farmers owning 75,201 operational ponds and occupying 1,309 hectares (13,090,740 m^2). Furthermore, since limited resources are allocated to collect data from fisheries related activities, national statistics often underreport small-scale fisheries and aquaculture production. Farmers face multiple challenges because of the highly fragmented value chain, including limited

TABLE 2 Selected private sector investors in the aquaculture value chain in Kenya (IDH, 2023).

• *Victory Farms*: Victory Farms located in Sindo in Homa Bay, for example, is one of success stories of cage aquaculture in sub-Saharan Africa. The company is on track to produce around 20,000 tonnes of fish by 2023, working with over 20,000 market trading women who source from its 55 branches countrywide to supply to their consumers
• *Jewlet Enterprises*: Established in 2010 and located in the Western region of Kenya with a vision to become a leading freshwater aquaculture farm in EA region. Jewlet is involved in the production of fingerlings and market-size tilapia fish using RAS, ponds, and cages. The average fingerling production in the facility is currently at 500,000 fingerlings per month. The company has heavily invested in research and technology and currently uses Genetically Improved Farmed Tilapia (GIFT) in the production of fingerlings
• *Kamuthanga Farm Limited*: Located in the Eastern region, Kamuthanga is an EcoMark Africa certified farm that leverages RAS in the production of fingerlings and market-size fish. For instance, Kamuthanga Fish farm based in Machakos County was established in 2014 as a large-scale commercial RAS and currently produces approximately 100 metric tonnes of tilapia and 3 million fingerlings annually (IDH, 2023)
• *Hydro Victoria Fish Hatchery Farm (HVFHF)*: A private investment firm established in November 2016, with initial investments in pond and cage fish farming in Busia and Siaya Counties. Realizing the gaps in fish seed and feeds, the firm set up a hatchery and nursing system with an annual production capacity of 2,500,000 tilapia fingerling in March 2019 based at Port Victoria Town, Busia County. The goal of the firm is to use black soldier fly (BSF) as an environmentally friendly, sustainable, and economically viable fish feed to create job opportunities for women and youths
• *Aquaculture Academy (AA)*: This is the knowledge arm of Lattice Aquaculture established in 2021 with the goal to train and build 'aquapreneurs' able to run a sustainable and profitable business, inspire others to become fish farmers and spur economic prosperity throughout the sector. The academy currently has two locations at Kamuthanga Fish Farm located in Machakos county and Jewlet Fish farms in Homabay County. The academy is structured to provide both theoretical and practical training to fish farmers, with a target to reach about 1,000 farmers every year
• *Aquarech Limited*: This is a fish aggregation company established in 2019 in Kisumu, Kenya. Aquarech is building Africa's first fish farming platform leveraging on technology to enhance access to inputs, credit and facilitate market. Through the platform, fish farmers can buy top-quality feed, sell fish, and learn about best fish farming practices to improve their incomes. The company estimates its outreach to be about 2,000 farmers, 60% of whom are cage farmers
• *Tunga Nutrition (K) Limited*: Established in 2021 as a joint venture between Unga Group Ltd., Nutreco International BV's Aqua division, Skretting to provide quality fish feed to meet the growing demand of feeds in the wider East African region. The company has a production plant located in Nairobi with over 35 distribution outlets spread out in the region. The company is involved in the manufacturing, importation marketing, and distribution of fish feed
• *Great Lakes Feeds Limited*: A registered company located in Utonga Beach, Bondo, Siaya County. The company is a social for-profit enterprise which has been operating for the last 5 years. The company is engaged in the production of high-quality animal feeds majorly fish feeds, but also poultry, pig feeds and others. The company established a hatchery facility in 2020 specializing in Nile tilapia (*Oreochromis niloticus*) and African catfish (*Clarius gariepinus*) fingerlings and brood-stock production and sale
• *Labedcash Marine Enterprises*: Fish and fingerlings production farm in Malava, Kakamega County. The hatchery has been in operation for the last 12 years. The farm specializes in commercial production of Nile Tilapia (*Oreochromis niloticus*), African catfish (*Clarias gariepinus*) fingerlings and ornamental. The farm has over 200 ponds and a hatchery that can produce up to 1 million fingerlings monthly
• *African Blue Limited* is producing very fresh and high-quality tilapia in cages in the clear and pristine waters of Lake Victoria. The company which was established in 2019 is located next to Uyawi Beach in Siaya County, Western Kenya, 15 km south of Bondo The company employs local community members to boost the Kenyan economy

access to quality and cost-effective inputs and premium markets. Since land and water are becoming scarce due to competition from other industries and resource users, technological advancements have been encouraged to accelerate aquaculture development (Obiero et al., 2019c). Recirculating aquaculture systems (RAS), tank-based systems, hydroponics, aquaponics, and installation of high-density cages in Lake Victoria are examples of technological innovations rolled out in recent years. However, the high initial investment costs, operating expenditures, and lower market pricing for farmed fish limit upscaling of RAS and other tank-based systems. Economic feasibility is frequently unsure due to the high investment prices, which may limit the adoption of these contemporary production systems, as seen in other locations (Ngoc et al., 2016).

In Kenya, cage culture has grown from relative obscurity over the past 10 years to become a significant method of producing Nile tilapia, primarily in rural and urban regions (Aura et al., 2018). Cage installations have spread throughout the five riparian counties, but their installation in terms of volume varies from county to county (Njiru et al., 2019). There are currently an estimated 4,800 active cages with a production capacity of 21,000 tonnes, but the projected carrying capacity using the best management practices is 110,000 tonnes annually (KMFRI, 2017). Even though cage culture holds great promise for boosting output, generating employment opportunities, and enhancing the economic wellbeing of rural communities, site suitability for installing cage is still poorly regulated. Over 45% of cage installations are made within 200 meters of fish breeding grounds, which may put other lake users in conflict (Njiru et al., 2019). Small

water bodies (SWBs), such as dams and reservoirs, also provide a variety of livelihood options in Kenya, significantly contributing to economic growth, food security, and national development (Aura et al., 2022). Aura et al. (2021) calculated the carrying capacity of 74 SWBs in Western and Central Kenya. The study demonstrated that the central region had a capacity to produce 72,447 tonnes in 37 sampled SWBs, while the western region would only produce approximately 447 tonnes in the sampled sites.

4. Role and contribution of national and county governments in aquaculture growth in Kenya

National and county governments support aquaculture development through enacting and enforcing laws and regulations. According to Part 1 of Section 29 of the Fourth Schedule of the Constitution, the National Government is responsible for the "protection of the environment and natural resources with a view to establishing a durable and sustainable system of development." On the other hand, county governments are responsible for implementing national government policies that pertain to their respective counties (CoK, 2010). National and county governments prioritize and support the implementation of aquaculture policies and measures that advance, support, and increase sector production (Tracy et al., 2021). To ensure uniformity and national standards in the fisheries and aquaculture sector, each County government implements and play their role in accordance with national policy guidelines through legislation and administrative action (CoK, 2010).

Fisheries and aquaculture are being developed by a number of government institutions and organizations through policy development and implementation, training, research, and extension. These organizations have been implementing their mandate either independently or in cooperation with other state organizations. In areas with high potential for aquaculture, there are both research and extension facilities; however, a lack of funding to support the facilities and staff has hindered their effectiveness in providing services (Obwanga and Lewo, 2017). The government also collaborates with non-governmental organizations (NGOs) to spearhead the research agenda, provide funding, conduct research, and produce and disseminate research findings. The focus of NGOs involvement in educating farmers, extension agents, and research officers about a range of aquaculture subjects, such as market access, entrepreneurship, and value addition, has been on the development of simple, appropriate technologies and innovations, particularly at the rural level (Fonda et al., 2021; Obiero et al., 2021).

4.1. National government

In general, the national government has developed policies and measures to promote aquaculture development (GoK, 2015). In addition, the government has established a number of support services, such as extension services, fish health programs, and fishery management programs, as well as resources for infrastructure development and marketing operations (Orina et al., 2018). The Kenyan government approved funding of KES 1 billion in November 2022 to establish the Kabonyo Fisheries and Aquaculture Service and Training Centre of Excellence. The goal of the centre is to support training, research, innovation, and best practices in aquaculture through practical demonstrations and business incubations. A Nile Perch Development Center, an Aquaculture Resource Center, and the Kenya Fishing School will be built as part of the project. Domestication and selective breeding of Nile perch, tilapia, and catfish will also be conducted to increase the number of fish species available to small and large-scale fish farmers. The National Aquaculture Technology Development and Innovation Transfer Centre in Sagana is also being expanded and modernized as a national breeding nucleus for warm water culture species. There are also several county-level fish multiplication hatcheries, research centers throughout the country, the National Trout Hatchery at Kiganjo, several universities and technical and vocational education centers, and private sector investments in aquaculture infrastructure.

4.2. County governments

The Kenyan Constitution of 2010 fundamentally changed the country's governance system. The constitution established 47 Counties and delegated many functions of the National Government to them. Counties are semi-autonomous administrative units in charge of county legislation, executive duties, and public service delivery. As a result of the current division of responsibilities between the National Government and the Counties, they play an important role in the growth of the agriculture industry and the provision of related services. Furthermore, counties have positioned themselves as focal points for accelerating socioeconomic development across the country, with most of it reliant on the agri-food sector (Coninx and Kilelu, 2020). County governments are responsible for developing industry-supporting regulations and policies, promoting aquaculture product production and marketing, and allocating resources such as land and water to the sector (Odende et al., 2022). They are also in charge of providing infrastructure and services such as roads, energy, and market access to help the country's aquaculture industry grow. County governments are also responsible for promoting research and development, developing expertise, and providing financial and technical assistance to the aquaculture sector. County governments mobilize farmers, provide extension services, build market connections, build access roads, promote fish consumption, and promote fish quality sanitary standards and programs (Muwonge et al., 2022).

Several counties have invested in aquaculture development programs and initiatives through various projects. For instance, Busia County, through the directorate of fisheries, has put a lot of efforts and resources in promoting aquaculture as a business both in the lake through open water cage culture systems and aquaculture parks on land systems to meet the growing population and demand for fish as a food and protein source (Odende et al., 2022). The county has introduced cage fish farming in Bunyala and Samia sub counties in Lake Victoria waters to increase fish production and so far over 100 cages have been installed in the Lake Victoria waters of Busia County. Additionally, the land-based aqua park has been constructed in Kamarinyang' in Teso South Sub-county (100 fish ponds), ATC Aquapark in Matayos Sub-county (20 fish ponds), Bukani, Samia Sub-county (100 fish ponds), and Siunga in Butula Sub-county (70 fish

ponds).[1] With the creation of these aqua parks by the County Government of Busia, fish production is estimated to increase from the current 1,080 MT valued at KES 200 million annually to at least 4,300 MT valued at KES. 1 billion by 2027 (see Footnote 1). This will also lead to increase in *per capita* fish consumption, improved income and trade in the county and reduced fishing pressure on the lake. In Kakamega County, a fish farming subsidy program for fish feeds and fingerlings has been launched to economically empower fish farmers and increase production of fish.

The County Government of Nyeri has actively extended support to fish farmers through various channels- providing fingerlings, feeds, dam liners and training. Nyeri County Government has facilitated the restocking of 266,000 fingerlings and supplied 16,825 Kg of feed to 3,000 farmers to enhance their operations. Further, these farmers have been equipped with 287 pond liners, which serve as essential equipment for their fish farming activities (CoG, 2023). Kisii County Government has embarked on an ambitious fish farming project to boost food security and improve earnings to farmers. Through the fisheries department, Kisii county government targets to construct 288 fish ponds in a project set to cost KES. 57 million (KCG, 2022). The objective of the initiative is to commercialize fish farming while improving food security. Kirinyaga County Government has supported 20 selected self-help groups with fishpond liners, fingerlings and feeds to enable them undertake fish farming through the Wezesha Kirinyaga Economic program that has been supporting farmers to diversify on their agricultural activities in order to increase their revenue streams (CGK, 2023). The project was informed by the huge deficit of fish which makes Kenya import fish since lake fishing cannot sustain the demand. All these comprehensive interventions in the above few highlighted county governments are carefully designed to empower fish farmers, enabling them to significantly improve their productivity and achieve greater success in the aquaculture sector. Devolution of government services has improved the efficiency of service provision to the Kenyan population, leading to several development projects in various parts of the country, especially in rural areas which are dominated by small-scale farming (Shimengah, 2018; Muwonge et al., 2022).

5. Donor supported aquaculture projects

Since the aquaculture industry was established in Kenya prior to independence, it has received significant support from the Government of Kenya (GoK), non-governmental organizations (NGOs), and bilateral and multilateral donor initiatives (Obwanga and Lewo, 2017). In recent years, donor funded support has shifted to commercialization of aquaculture through propagation of catfish and production of tilapia fingerlings as well as to establishment of semi-intensive and intensive culture systems. Although projects supported by bilateral and multilateral organizations have historically been marked by giveaways, subsidies, and other forms of assistance, farmers' over-reliance on free and/or subsidized inputs and services is one of their major challenges. Because of this, farmers have had a difficult time getting long-term autonomy, which has slowed the growth of the sub-sector. Therefore, incorporating donor supported programs into GoK activities has improved the initiatives' and programs' sustainability (Ngugi and Manyala, 2009).

According to Ngugi and Manyala (2009), ten donors contributed USD 13.25 million to Kenya's aquaculture industry between 1970 and 1990. Since 2000, the UK's Department for International Development (DFID), the Swedish International Development Cooperation Agency (SIDA), and other bilateral and multilateral donor organizations have funded aquaculture development projects. Furthermore, in 2010 there were reports of direct investments from Australia (USD 198.4 million), Israel (USD 49.6 million), the United Kingdom (USD 9.2 million), and India (USD 5.4 million) (Rothuis et al., 2011). The increased investments are also due to several non-governmental organizations support for technology transfers for improved fish farming practices. For example, since the 1990s, the USAID-funded Aquaculture CRSP in Kenya has been instrumental in advancing innovative fish production techniques. Donor support for aquaculture in Kenya is expected to promote long-term growth by giving small-scale producers access to financing, building their capacity, and providing technical assistance (Kaminski et al., 2018; ASDSP, 2019).

5.1. Selected donor funded aquaculture initiatives

Previously, three major donor-funded projects in Kenya were implemented, including the Lake Victoria Environmental Management Project (LVEMP), Trilateral Cooperation, and Kenya Market-Led Aquaculture Program (KMAP) programs in specific Kenyan counties. The lessons and results from these projects can be used to build on, expand, and improve future projects so that the benefits can reach a larger number of rural smallholder farmers in a sustainable way.

5.1.1. Lake Victoria Environment Management Program (LVEMP)

LVEMP was implemented to deal with the observed environmental problems experienced in the Lake Victoria basin (LVEMP, 2002). It did this by drawing the attention of East African Community (EAC) partner states and other stakeholders' attention to issues that threaten sustainable development, the use of lake basin resources, and the strengthening of governing institutions (Kolding et al., 2005; Mwanuzi et al., 2005). The goal of the project was to create a thriving society with fair opportunities and rewards in a healthy and sustainable manner. The LVEMP was implemented in two phases. Phase I from March 1997 to December 2005, and Phase II from September 2009 to December 2017. The World Bank (WB) funded Phase I through grants from the Global Environment Facility (GEF) and credits from the International Development Association (IDA). LVEMP II, which succeeded LVEMP I, aimed to reduce widespread poverty and improve people's quality of life by promoting sustainable management of the Lake Victoria Basin's shared natural resources. According to a 2018 World Bank report on aquaculture issues, LVEMP helped create (a) the East African Community's Fisheries and Aquaculture Policy (LVFO, 2018a), (b) the guidelines for setting up and operating cage fish farming in the EAC (LVFO, 2018b), (c) Harmonized Fisheries and Aquaculture Border Inspection Manual (LVFO, 2018c), and (d) Regional fishing

1 https://busiacounty.go.ke/index.php/fisheries

guidelines for species-specific licenses for Lake Victoria (LVFO, 2015). The new fisheries policy frameworks have been adopted at the national level in the three countries, especially in Kenya to facilitate implementation of the Fisheries Management and Development Act No. 35 (2016) (Bwathondi et al., 2014).

5.1.2. Kenya Aquaculture Productivity and Agribusiness Program (KAPAP)

The Kenyan Government in partnership with the World Bank and other partners supported the implementation of the KAPAP project to promote the growth of the country's aquaculture sector. The actual cost was $70.31 million, out of which the beneficiary communities contributed $0.57 million, $65.95 million in IDA credit, and $3.79 million in government funding over a five-year period (2009–2015). KAPAP aimed to "increase agricultural productivity and the incomes of participating smallholder farmers" in the project regions. Under the Competitive Grant System, the project also funded projects in the aquaculture value chain titled "Commercializing aquaculture production through sustainable technologies and market linkages." The goal of the aquaculture project was to establish a thriving and sustainable commercial aquaculture among rural impoverished people to improve livelihood, wealth development, and food safety and security. The overarching goal was to promote acceptable post-harvest handling techniques, increase productivity, and create market and information-sharing channels for Tilapia, Catfish, and *Ningu*. The project made significant progress in several areas, including the production and distribution of improved tilapia and catfish seed in 22 Kenyan counties; the formulation and production of 12 new fish feed diets for different developmental stages of tilapia, catfish, and *Ningu*; the development and adoption of 13 value-added farmed fish products; and the development of a web-based system to connect aquaculture farmers with different stakeholders by developing a web-based system to link aquaculture farmers with markets; capacity building and training of 287 aquaculture trainers and 922 fish farmers countrywide on different aquaculture systems and technologies; development of publications and value use documents; and organizing Eat More Fish campaigns in Kisii and Taita Taveta Counties (World Bank, 2018).

5.1.3. Trilateral Cooperation (TTC)

The TTC was a joint project implemented by Kenya, Germany, and Israel from 2012 to 2016. Its goal was to increase commercial aquaculture capacity through a targeted skills development program in aquaculture value chain technologies in the Lake Victoria region. The TTC pioneered an efficient and low-cost method of educating 8,000 farmers by selecting and outfitting the training facility, educating trainers including instructors, extension officers, and experienced farmers, and requesting farmers to contribute to the cost of education in order to secure their commitment. Students' understanding of aquaculture, aquafeeds, and fingerling production improved as a result of this educational strategy (Ngugi et al., 2013).

5.1.4. Kenya Market Led Aquaculture Program (KMAP)

KMAP was a four-year project (January 2016 to December 2019) funded by the Embassy of the Kingdom of the Netherlands in Kenya at a cost of EUR 4 million to address triple challenges in food production, i.e., food insecurity, nutrition, and income by engaging 1,100 fish farming enterprises in Kenya (Farm Africa, 2019). The program adopted a franchise model to create a commercially viable input and service distribution system comprised of aqua shops owned by local entrepreneurs that provided inputs and technical advice on best management practices in fish farming. Furthermore, the project engaged over 8,000 small-scale fish farmers by supporting household food needs and providing intermittent income from sale of fish surpluses. Building on the momentum created by KMAP, another Dutch funded public-private partnership (PPP) project, FoodTechAfrica combined the strengths of Dutch agrifood companies (primarily SMEs), knowledge institutions, government agencies, and their East African counterparts to improve food security in East Africa by establishing a fully integrated aquaculture supply chain (IDH, 2023). This project's contribution to Kenya's aquaculture sector cannot be overlooked, particularly in terms of transitioning mindset of smallholder farmers from subsistence to commercial aquaculture enterprises in rural communities. Furthermore, fish farmers were encouraged to invest in aquaculture by showcasing successful fish production systems and connecting them with experts to establish and operate these systems (KMAP, 2016).

5.2. Ongoing donor support aquaculture initiatives

5.2.1. EU-EAC project for promoting aquaculture in the Lake Victoria Basin (TRUE-FISH)

The True Fish Farming Story in the Lake Victoria Basin (TRUE-FISH) is a project financed under the 11th European Development Fund for a 5-year period (2019–2024) at a total cost of EUR10.15 million for the benefit of EAC countries, Kenya, Tanzania, and Uganda (LVFO, 2019). The main objective is to foster competitive, gender-equitable, and sustainable commercial aquaculture development in order to promote economic growth and long-term resource management in the Lake Victoria basin (Applestein et al., 2022). The overarching goal of the project is "to contribute to the development of a competitive, gender-equitable, and sustainable commercial aquaculture sector to support the economic development and sustainable management of natural resources in the Lake Victoria Basin." The project focuses on three specific objectives: 1) Improve capability in access to commercial networks at the national and regional levels for aquaculture-related businesses, 2) Build national capacity to use robust genetic screening consequently increase availability of skilled personnel thus addressing two of the most significant limiting factors for aquaculture development, and 3) Improve sustainability by mitigating risks related to the aquatic environment. To minimize the risk of accidental and/or intentional introduction of genetic material that could endanger native species, component 3.3 of the project is intended to deliver improved protection of biodiversity of the aquatic resources of the region (LVFO, 2019).

5.2.2. Kenya Climate Smart Agriculture Project (KCSAP)

The Government of Kenyan (GoK) acquired an International Development Association (IDA) credit facility from the World Bank amounting to US$250 million to finance the Kenya Climate Smart agriculture Project (KCSAP) for a five-year period (2017–2022),

though the deadline was extended to 2023 due to the Covid-19 pandemic. The total cost of the project is US$ 279 million with a Government contribution of US$ 29 million. The project activities are implemented within five (5) components, namely (i) upscaling climate-smart agriculture practices, (ii) strengthening climate smart agricultural research and seed systems, (iii) supporting agro-weather, market, climate, and advisory services, (iv) project coordination and management; and contingency emergency services. Within Component 2, KCSAP developed, validated, and adopted context-specific climate smart-aquaculture technologies, innovations, and management practices (CSA-TIMPs) to target beneficiaries under Components 1 and 3 in 24 counties, as well as developed sustainable seed production and distribution systems. The project provided collaborative research grants (CRGs) to support implementation of adaptive and applied research through the Kenya Agriculture and Livestock Research Organization (KALRO)-led National Agricultural Research Systems (NARS) framework. The CRGs funded six (6) applied research projects, four (4) seed systems projects, and six (6) adaptive research projects within the aquaculture value chain to increase food and nutrition security in the counties of Busia, Siaya, Kakamega, Nyandarua, Isiolo, Marsabit, and Lamu. CSA-TIMPs development was followed by the creation of technical training materials and modules on the CSA-TIMPs, as well as subsequent training of community technical departments and service providers for effective CSA-TIMPs delivery. In the aquaculture value chain, the project inventoried 50 CSA-TIMPs and developed Training of Trainor (ToT) manuals and value use documents for training over 500 extension service providers and 2,500 lead and smallholder farmers (Obiero et al., 2021). The CSA-TIMPs were divided into six categories: (a) culture systems, (b) culture species and breeding, (c) fish feeds, nutrition, and feed management practices, (d) fish health management and biosecurity, (e) post-harvest loss reduction, (f) value addition, and (g) fish marketing, trade, and supply channels (Obiero et al., 2021). Furthermore, KCSAP has provided funding for sub-projects throughout the aquaculture value chain with the goal of increasing fish productivity and resistance to the hazards of climate change.

5.2.3. Aquaculture Business Development Program (ABDP)

The Aquaculture Business Development Program (ABDP) is a partnership between the Government of Kenya and the International Fund for Agricultural Development (IFAD), with the overall goal to contribute to the reduction of poverty and increased food security and nutrition in rural communities in Kenya (ABDP, 2021). The ABDP is being implemented for an eight-year period, from 2018 to 2026, with a total budget of US$ 143.3 million, which is approximately KES. 14.9 billion. The Program Development Objective is "to increase the incomes, food security and nutritional status of the wider communities of poor rural households involved in aquaculture in the target Counties." The Program targeted counties with high aquaculture activity, adequate research, processing and marketing infrastructure, and suitable aquatic resources (Obiero et al., 2019c). The Program began in six (6) Counties in the first year and has since expanded to a total of fifteen (15) counties, including Busia, Embu, Homa Bay, Kajiado, Kakamega, Kiambu, Kirinyaga, Kisii, Kisumu, Machakos, Meru, Migori, Nyeri, Siaya and Tharaka Nithi (ABDP, 2021).

The ABDP is comprised of two investment components aimed to strengthen the aquaculture value chains for the benefit of smallholder fish producers, service providers and rural communities. The program targets 35,500 households of aquaculture farmers, including 5,500 youth beneficiaries. According to third joint IFAD/GoK supervision and implementation support mission (ISM), the project has made some progress towards achieving the development objectives, but the implementation pace is slow and achievements in most cases falls short of the targets. The project has realized some progress in achieving its development objective. For instance, "the cumulative fish production from ponds was about 176,586 Kg while 53,957 Kgs were produced from dams that have received some support from the project. This translates to income from fish sales of about KES 64 million (approximately USD 557,000) from fish ponds and KES 19,576,050 (approximately USD 170,000) from dams, respectively" (IFAD, 2022). In general, progress has been experienced in various farm-level activities mainly in provision of pond liners to prevent water loss and predator control nets. Specifically, 9,420 farmers received a pond liner (3,973), or predator kit (5,447) and 6,291 farmers built, upgraded, or rehabilitated their ponds and stocked them with Tilapia, or Catfish fingerlings. The Program has also made significant investments to improve farmers' knowledge and skills in aquaculture through various approaches and interventions through extension support services and aquaculture field schools. Nonetheless, key value chain interventions are hampered by procurement-related issues and inefficient sequencing of project activities (IFAD, 2022).

5.2.4. Kenya Marine Fisheries and Socio-Economic Development (KEMSFED)

The Government of Kenyan in collaboration with the World Bank is implementing KEMFSED project through the State Department for Blue Economy and Fisheries. The project duration is 5 years (2020 to 2025) with a total cost of KES 10 billion. The PDO is being implemented in three complementary components: "(1) strengthen capacity in governance and management of marine fisheries, (2) Coastal community empowerment and livelihoods, and (3) project management. The project targets to support about 36,000 beneficiary households, 217,000 individual beneficiaries across 98 wards in five counties (Kwale, Kilifi, Lamu, Mombasa and Tana River). Currently, the project is fast tracking the developing of a marine hatchery—National Mariculture Training Centre (NAMARET) in Shimoni, which will incorporate a marine hatchery, wet and dry laboratory, training resource centre, administration block, accommodation, and museum. The marine hatchery is intended to provide a consistent supply of high-quality seed of finfish and shellfish for the growth of the industry. To step up mariculture farming, 27 extension officers, 43 fish (finfish and shellfish) and 60 sea-weed farmers were trained in mariculture production, while 6 ponds for three groups in Kilifi County were stocked with prawns and marine tilapia (KEMSFED, 2022).

5.3. Role of national and international research organizations

5.3.1. WorldFish

Since its inception in 1975 at the University of Hawaii as the International Center for Living Aquatic Resources Management (ICLARM), WorldFish initially focused on enhancing productivity of coastal fisheries and aquaculture through institutional and

technological interventions in Southeast Asia and the Pacific. WorldFish is playing a significant role in bringing attention to issues revolving around the contribution of small-scale fisheries and aquaculture to food and nutrition security, as a member of the Consultative Group on International Agricultural Research (One CGIAR) and the sole global research center with over 45 years of experience in low- and middle-income countries (WorldFish, 2020; Kura and Kawarazuka, 2021). The original mandate has been expanded to include broader aspects of aquatic food systems and their essential role in sustaining human well-being and livelihoods. WorldFish has a long history of working in Africa, including the establishment of country offices in Egypt, Nigeria, Tanzania, and Zambia, in order to strengthen the continent's aquaculture sector through research and training.

WorldFish in partnership with ICIPE, CORAF, Aller Aqua, Swedish University of Agricultural Sciences and Natural Resource Development College is implementing a new project *Development and Scaling of Sustainable Feeds for Resilient Aquatic Food Systems in Africa (FASA)"* that seeks to develop low-cost, highly nutritious fish feeds based on novel ingredients and enable 5,000 smallholder fish farmers in 3 African countries – Nigeria, Zambia, and Kenya to test and adopt these ingredients and feeds, leading to increased income, improved food security, and reduced waste and pollution. Specifically, FASA expected outcomes in Kenya include: (i) Enhanced capacity of stakeholder groups in Kenya to integrate best practices toward a more sustainable feed sector, and to adopt new knowledge on nutrient requirements of multiple improved strains of tilapia and African catfish, (ii) Established the quality of at least 5 local ingredients for improvement through various processing techniques and the ingredients that are used by stakeholders in Kenya, including local millers and farmers, to produce 9 novel, cost-efficient insect-based feed formulations, to improve aquaculture productivity and resilience, (iii) Develop databases and digital solutions to be used by farmers for formulating and adapting new insect- based local feeds on a "real-time" basis, and (iv) 3,000 farmers directly or indirectly linked to the project access, test, and use novel fish feeds and feed solutions using the knowledge and innovations developed by the project, with the support of a range of strategic scaling partners and other stakeholders.

5.3.2. International Centre of Insect Physiology and Ecology (*icipe*)

The International Centre of Insect Physiology and Ecology (*icipe*) is a Pan-African Center of Excellence in insect and arthropod research. Over the past 50 years, *icipe* has pioneered and applied world class science and innovation to address issues related to food and nutrition security, human and environmental health for the continent's rural and urban communities (Icipe, 2020). The Center conducts state of the art research on the use of insects for food, feed, and other applications, and then applies this knowledge to create creative, cost-effective, accessible, and simple solutions to address food insecurity and malnutrition while promoting mitigation action to lower greenhouse gas emissions (Kelemu et al., 2015). These initiatives have been aided by a vast collaboration network, extensive capacity- and awareness-building, the adoption of national rules and standards, and fostering of marketing alliances for insect goods, particularly those derived from black soldier flies, in Kenya and East Africa. Since insect-based businesses can be operated with minimal labor inputs, they are ideal for women, young people, and low-income households, who frequently constrained by inadequate access to agricultural resources. In response to these research opportunities and needs, ICIPE established the Insects for Food, Feed and Other Uses Program (INSEFF) to translate the latent benefits of insects in transforming the food system into sustainable and viable circular economy (Tanga et al., 2021). To this end, several medium- to large-scale black soldier fly (BSF) farms have been established (Tanga et al., 2021). Furthermore, ICIPE collaborates with its partners to promote insect-based farming enterprises. Some of the projects include:

- *SiPFeed*: Testing Business Models for Scaling Insect-Based Protein Feed for Use in Poultry Farming and Aquaculture in Kenya, funded by Rockefeller Foundation; whose objective is "to implement and promote the use of insect-based protein as feed additives in poultry and aquaculture among smallholder farmers, small- and medium-scale enterprises (SMEs) and other actors along the value chain."
- *INSFEED*: Insect feed for poultry, fish and pig production in sub-Saharan Africa – Phase 1&2 funded by International Development Research Centre, Canada (IDRC) and Australia Centre for International Agricultural Research (ACIAR).
- *PROTeinAfrica*: Upscaling the benefits of insect animal feed technologies for sustainable agriculture intensification in Africa funded by the ACIAR.
- *ILIPA*: Improving livelihood by increasing livestock production in Africa: An agribusiness model to commercially produce high quality insect-based protein ingredients for chicken, fish and pig industries.
- *INSFeedFish*: Upscaling insect-based protein-rich feeds for enhanced nutrition and health of fish in Kenya, funded by KCSAP. The specific objectives were to: (i) evaluate the viability of insect-based fish feeds, (ii) validate mass production, harvesting, and primary processing of protein from black soldier fly larvae, (iii) validate ration formulations for nutrient-rich insect-based feeds for fish production, and (iv) validate production protocols for safe insect-based fish feeds/diets in accordance with established standards in Busia, Siaya, and Kakamega.

6. Conclusions and priorities for action

The aquaculture sector in Kenya is gaining momentum due to rapid population and economic growth, increased awareness of the health benefits of eating fish, and changes in lifestyles and preferences brought about by rapid urbanization and globalization, among other factors. We successfully assessed the roles of multilateral development organizations, the public and private sectors in aquaculture development in Kenya. The study findings depict the significance of synergistic interventions from development organizations, the public and private sectors for the expansion of aquaculture output to meet the rising food demand in the country. The actors complement each other through the combined use of resources towards achieving the goal of aquaculture development for improved food and nutrition security. By letting the various actors focus on what they are good at, the quality of the service is strengthened. Government acts as the regulator and focuses on planning services and monitoring

performance. Both the national and county governments play critical roles with respect to the formulation of pro-aquaculture policies and creation of favorable financial environment for the potential investors in the sector. The public and private sectors complement the efforts of international donors and development agencies by investing more resources to policy research, aquaculture research and educational initiatives in the sector. In addition, international donors and development agencies' role should not be limited to technology transfer, and capacity building, but they should collaborate with the national and county governments in developing innovative financial models that favor sustainable aquaculture enterprises.

To unlock Kenya's aquaculture potential and improve its food and nutrition status, deliberate efforts must be taken to create a conducive environment for public and private investment in the industry. First, there is a need to coordinate and clearly articulate the roles and responsibilities among devolved and national governments, donors, and financial institutions through public-private partnerships to ensure optimal allocation of financial, human, and infrastructure resources. Second, more collaborative research should be devoted to design and construction of climate smart culture systems, developing new species to guarantee supply of high-quality products; develop and scale low cost and highly nutritious fish feeds based on novel ingredients; and to enhance resilient livelihoods through innovative aquaculture practices and market linkages to create employment opportunities for youths and women. More importantly, research, training, extension, and advisory services should be strengthened to improve capability and preparedness for emergencies such as the recent fish kills in cages in Lake Victoria. Third, national and devolved governments should create an enabling policy environment through tax incentives and regulatory reforms to combat climate change, protect nature and biodiversity, sustain livelihoods, and mainstream food and nutrition initiatives into design of international financial institution supported projects. The county government can also build links between the private and public sectors through the County Integrated Development Plans (CIDPs) and allocate budgets to promote aquaculture development as a devolved function. Finally, private sector investment is critical for sustained aquaculture growth through creating innovative and inclusive financing mechanisms to increase access to financial services, such as micro credit to fund small aqua businesses. Hence, donors and funding agencies should focus on developing gender-inclusive and pro-youth interventions to increase employment opportunities and deliver value for money along the value chain nodes.

7. Limitations of the study

There were limitations in our research approach. First, regarding rigor and quality, the literature in our review covered an extensive spectrum. This, in our opinion, is a limitation of the review approach and is noted as such since scoping reviews do not evaluate the rigor or quality of studies (Hanneke et al., 2017). Second, when seeking to define the scope of the study, the incorporation of gray literature posed challenges. The challenge in defining the study scope was also a result of the heterogeneity in terminology and the ambiguous definitions of key terms. Although the scoping review process appears to be linear, following the five steps, Arksey and O'Malley (2005) state that the steps are "not linear but iterative." This view was supported by the iterative and sometimes repetitive nature of our scoping approach. The research questions, search technique, and selection criteria had to be defined and redefined in an iterative manner leading to increase in time and resources needed. Owing to the wide scope and unclear boundaries, we had a lot of data which presented challenges for feasibility as the process was tedious and took longer than expected. Third, in as much as we reduced reporting bias by engaging at least two reviewers in reviewing the full full-text and abstract of each article, the process still had a risk of bias of included literature.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

JMM, KOb, JI, CT, and RY put together the manuscript with contributions from all co-authors. All authors involved the literature review and conceptualization of the manuscript and read and approved to the published version.

Funding

This work was supported by the Kenya Climate-Smart Agriculture Project (KCSAP) Collaborative Adaptive Projects (Grant No. GA02-4/3, Grant No. GA02-4/4 & Grant No. GA02-4/5), Australian Centre for International Agricultural Research (ACIAR) (ProteinAfrica – Grant No: LS/2020/154), IKEA Foundation (G-2204-02144), Novo Nordic Foundation (ReflPro: NNF22SA0078466), the Rockefeller Foundation (WAVE-IN—Grant No: 2021 FOD 030); Bill & Melinda Gates Foundation (INV-032416); Horizon Europe (NESTLER - Project: 101060762 - HORIZON-CL6-2021-FARM2FORK-01), the Norwegian Agency for Development Cooperation (NORAD) (Grant No: SAFA-21/0004.), the Curt Bergfors Foundation Food Planet Prize Award; Norwegian Agency for Development Cooperation, the Section for research, innovation, and higher education [Grant number RAF–3058 KEN–18/0005 (CAP–Africa)]; the Swedish International Development Cooperation Agency (Sida); the Swiss Agency for Development and Cooperation (SDC); the Federal Democratic Republic of Ethiopia and the Government of the Republic of Kenya. The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the manuscript. The views expressed herein do not necessarily reflect the official opinion of the donors.

Acknowledgments

The authors appreciate the financial assistance from Kenya Climate-Smart Agriculture Project (KCSAP), Australian Centre for International Agricultural Research (ACIAR), IKEA Foundation, Novo Nordic Foundation, the Rockefeller Foundation, Bill & Melinda Gates Foundation, Horizon Europe, the Norwegian Agency for

Development Cooperation (NORAD), the Curt Bergfors Foundation Food Planet Prize Award, the Swedish International Development Cooperation Agency (Sida); the Swiss Agency for Development and Cooperation (SDC), Norwegian Agency for Development Cooperation, the Section for research, innovation, and higher education, the Federal Democratic Republic of Ethiopia and the Government of the Republic of Kenya.

Conflict of interest

RY was employed by WorldFish.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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